INSTRUCTION BY MAIL.

THE BUILDING TRADES POCKETBOOK

A HANDY MANUAL
OF REFERENCE ON

BUILDING CONSTRUCTION

INCLUDING
Structural Design, Masonry, Bricklaying, Carpentry,
Joinery, Roofing, Plastering, Painting,
Plumbing, Lighting, Heating,
and Ventilation

BY

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PREFACE.

This Pocketbook is intended for the use of all persons connected with The Building Trades, and contains many features not found in similar publications. In addition to tables giving the properties of materials used in construction, practical rules for laying out work, and data valuable for reference, it presents approved methods for solving the problems involving strength and stability, which occur in building practice. The processes of calculation are clear and intelligible, and those who are acquainted with simple arithmetic will have no difficulty in following them.

Among the subjects considered are the loads on structures; the strength of materials; the bearing capacity of soils; the width and thickness of footing courses; the dimensions of piers and their foundations; the thickness of walls for different classes of buildings; and the various kinds of stone and brick masonry. Careful analyses are made of columns, beams, and arches of iron, steel, wood, and stone, and of the design and

construction of roof trusses in wood and steel. The features of detail peculiar to structural work are also fully explained and illustrated.

Constructive details pertaining to Masonry, Bricklaying, Plastering, Carpentry, Joinery, Stairbuilding, Roofing, and Painting are treated comprehensively, and much new information is given on the Computation of Quantities and the Costs of Materials.

There is no other pocketbook published which fully treats of American Plumbing, Gas-fitting, Heating, and Ventilation. The chapters on these subjects contain tables, rules, formulas, recognized maxims, hints on the best modern practice and on the most approved apparatus and materials, with numerous sketches and practical information never before published.

The demand for a handy, serviceable volume devoted entirely to the building interests, has induced the production of "The Building Trades Pocketbook," and it will be found to be a valuable aid to Architects, Engineers, Contractors, Builders, and Artisans.

The International Correspondence Schools,

January 2, 1899. Scranton, Pa.

THE

BUILDING TRADES POCKETBOOK.

ARITHMETIC.

SIGNS USED IN CALCULATION.

$+$ *Plus*, indicates *addition;* thus, $10 + 5$ is 15.

$-$ *Minus*, indicates *subtraction;* thus, $10 - 5$ is 5.

$\times$ *Multiplied by*, indicates *multiplication;* thus, 10×5 is 50.

$\div$ *Divided by*, indicates *division;* thus, $10 \div 5$ is 2.

$=$ *Equal to*, indicates *equality;* thus, 12 in. = 1 ft.

$(\ )$, $[\ ]$, $\{\ \}$, called *parenthesis*, *bracket*, and *brace*, respectively, have the same meaning, and signify that the operations indicated within them are to be performed first; or, if more than one is used, that indicated in the inner one is to be effected first. Thus, in the expression $5(7-2)$, the subtraction is to be made before multiplying by 5. Again, in the expression $\frac{1}{2}\left[a+\left(b-\frac{c}{4}\right)\right]$, the subtraction indicated within the parenthesis is made first; the remainder is added to a, and one-half the sum found.

$\overline{\quad}$, called the *vinculum*, is used for the same purpose as the parenthesis, but chiefly in connection with the sign $\sqrt{\ }$; thus, $\sqrt{\quad}$.

. , called the *decimal point*, is placed in a number containing decimals, to fix the value of the number; thus, 12.5 is 12 and $\frac{5}{10}$; 1.25 is 1 and $\frac{25}{100}$; etc.

8^2 means that the number 8 is to be *squared;* thus, $8^2 = 8 \times 8 = 64$.

8^3 means that the number 8 is to be *cubed;* thus, $8^3 = 8 \times 8 \times 8 = 512$.

$\sqrt{}$, called the *radical sign*, means that some root of the expression under it is to be found; if used without a small index figure, it means square root; thus, $\sqrt{64} = 8$.

$\sqrt[3]{}$ $\sqrt[4]{}$ mean that the *cube* or the *fourth* root is to be found, the index figure indicating the root; thus, $\sqrt[3]{27} = 3$.

: : : : means proportion; thus, 3 : 4 : : 6 : 8 is read *3 is to 4 as 6 is to 8.* Instead of the : : sign, the equality sign = is often substituted; thus, 3 : 4 = 6 : 8.

° ′ ″ mean degrees, minutes, and seconds; as, 60° 15′ 15″, which is read *60 degrees, 15 minutes, 15 seconds.*

′ ″ also mean feet and inches; thus, 7′ 6″ is read *7 feet 6 inches.*

π (read *pi*) means the ratio of the circumference of a circle to the diameter and = 3.1416.

Σ (read *sigma*) means *summation;* thus, $\Sigma(a + b)$ means that there are several values for both a and b, and that the sum of all is to be found.

FRACTIONS.

It is taken for granted that the reader knows how to perform the common operations of addition, subtraction, etc., where only whole numbers are used; but, when there are mixed or fractional numbers, a little refreshment of the memory may be desirable to some; hence, a little space is devoted to this elementary branch of arithmetic.

COMMON FRACTIONS.

The *numerator* of a fraction is the number above the bar; and the *denominator* is the number beneath it; thus, in the fraction $\frac{3}{4}$, 3 is the numerator and 4 is the denominator. Two or more fractions having the same denominator are said to have a *common* denominator. By "reducing fractions to a common denominator" is meant finding such a denominator as will contain each of the given denominators without a

remainder, and multiplying each numerator by the number of times its denominator is contained in the common denominator. Thus, the fractions $\frac{1}{4}$, $\frac{7}{8}$, and $\frac{9}{16}$ have, as a common denominator, 16; then, $\frac{1}{4} = \frac{4}{16}$; $\frac{7}{8} = \frac{14}{16}$; $\frac{9}{16} = \frac{9}{16}$.

By "reducing a fraction to its lowest terms" is meant dividing both numerator and denominator by the greatest number that each will contain without a remainder; for example, in $\frac{14}{16}$, the greatest number that will thus divide 14 and 16 is 2; so that, $\frac{14 \div 2}{16 \div 2} = \frac{7}{8}$, which is $\frac{14}{16}$ reduced to the lowest terms.

A *mixed* number is one consisting of a whole number and a fraction, as $7\frac{3}{8}$.

An *improper* fraction is one in which the numerator is equal to, or greater than, the denominator, as $\frac{17}{8}$. This is reduced to a mixed number by dividing 17 by 8, giving $2\frac{1}{8}$. If the numerator is less than the denominator, the fraction is termed *proper*. A mixed number is reduced to a fraction by multiplying the whole number by the denominator, adding the numerator, and placing the sum over the denominator; thus, $1\frac{7}{8} = \frac{(1 \times 8) + 7}{8} = \frac{15}{8}$.

To add fractions or mixed numbers. If fractions only, reduce them to a common denominator, add partial results, and reduce sum to a whole or mixed number. If mixed numbers are to be added, add the sum of the fractions to that of the whole numbers; thus, $1\frac{7}{8} + 2\frac{1}{4} = (1 + 2) + (\frac{7}{8} + \frac{2}{8}) = 4\frac{1}{8}$.

To subtract two fractions or mixed numbers. If they are fractions only, reduce them to a common denominator, take less from greater, and reduce result; as, $\frac{7}{8}$ in. $- \frac{9}{16}$ in. $= \frac{14 - 9}{16} = \frac{5}{16}$ in. If they are mixed numbers, subtract fractions and whole numbers separately, placing remainders beside one another; thus, $3\frac{7}{8}$ in. $- 2\frac{1}{4}$ in. $= (3 - 2) + (\frac{7}{8} - \frac{2}{8}) = 1\frac{5}{8}$ in. With fractions like the following, proceed as indicated: $3\frac{7}{16}$ in. $- 1\frac{13}{16}$ in. $= (2 + \frac{16}{16} + \frac{7}{16}) - 1\frac{13}{16} = 2\frac{23}{16} - 1\frac{13}{16} = 1\frac{10}{16} = 1\frac{5}{8}$ in.; 7 in. $- 4\frac{3}{4}$ in. $= (6 + \frac{4}{4}) - 4\frac{3}{4} = 2\frac{1}{4}$ in.

To multiply fractions. Multiply the numerators together, and likewise the denominators, and divide the former by the

latter; thus, $\frac{1}{2}$ in. $\times \frac{3}{4}$ in. $\times \frac{5}{8}$ in. $= \frac{1 \times 3 \times 5}{2 \times 4 \times 8} = \frac{15}{64}$ cu. in. If mixed numbers are to be multiplied, reduce them to fractions, and proceed as above shown; thus, $1\frac{1}{2}$ in. $\times 3\frac{1}{4}$ in. $= \frac{3}{2} \times \frac{13}{4} = \frac{39}{8} = 4\frac{7}{8}$ sq. in.

To divide fractions. Invert the divisor (i. e., exchange places of numerator and denominator) and multiply the dividend by it, reducing the result, if necessary; thus, $\frac{7}{8} \div \frac{3}{4} = \frac{7}{8} \times \frac{4}{3} = \frac{28}{24} = \frac{7}{6} = 1\frac{1}{6}$. If there are mixed numbers, reduce them to fractions, and then divide as just shown; thus, $1\frac{5}{8} \div 3\frac{1}{4} = \frac{13}{8} \div \frac{13}{4}$, or $\frac{13}{8} \times \frac{4}{13} = \frac{52}{104} = \frac{1}{2}$.

DECIMAL FRACTIONS.

In decimals, whole numbers are divided into tenths, hundredths, etc.; thus, $\frac{1}{10}$ is written .1; .08 is read $\frac{8}{100}$, the value of the number being indicated by the position of the decimal point; that is, one figure after the decimal point is read as so many tenths; two figures as so many hundredths; etc. Moving the decimal point to the right multiplies the number by 10 for every place the point is moved; moving it to the left divides the number by 10 for every place the point is moved. Thus, in 125.78 (read 125 and $\frac{78}{100}$), if the decimal point is moved one place to the right, the result is 1,257.8, which is 10 times the first number; or, if the point is moved to the left one place, the result is 12.578 which is $\frac{1}{10}$ the first number, moving the point being equivalent to dividing 125.78 by 10.

Annexing a cipher to the right of a decimal does not change its value; but each cipher inserted between the decimal point and the decimal divides the decimal by 10; thus, in 125.078, the decimal part is $\frac{1}{10}$ of .78.

To add decimals. Place the numbers so that the decimal points are in a vertical line, and add in the ordinary way, placing the decimal point of the sum under the other points.

$$\begin{array}{r} 101.257 \\ 12.965 \\ 43.005 \\ 920.600 \\ \hline 1{,}077.827 \end{array}$$

To subtract decimals. Place the number to be subtracted with its decimal point under that of the other number, and subtract in the ordinary way.

$$\begin{array}{r} 917.678 \\ 482.710 \\ \hline 434.968 \end{array}$$

To multiply decimals. Multiply in the ordinary way, and point off from the right of the result as many figures as there are figures to the right of the decimal points in *both* numbers multiplied; thus, in the example here given, there are three figures to the right of the points, and that many are pointed off in the result. If either number contains no decimal, point off as many places as are in the number that does.

$$\begin{array}{r} 21.72 \\ 34.1 \\ \hline 2172 \\ 8688 \\ 6516 \\ \hline 740.652 \end{array}$$

If a result has not as many figures as the sum of the decimal places in the numbers multiplied, prefix enough ciphers before the figures to make up the required number of places, and place the decimal point before the ciphers. Thus, in .002 $\times$ .002, the product of $2 \times 2 = 4$; but there are three places in each number; hence, the product must have *six* places, and five ciphers must be prefixed to the 4, which gives .000004.

To divide decimals. Divide in the usual way. If the dividend has *more* decimal places than the divisor, point off, from the right of the quotient, the number of places in *excess*. If it has *less* than the divisor, annex as many ciphers to the decimal as are necessary to give the dividend as many places as there are in the divisor; the quotient will then have *no* decimal places. For example, $\frac{25.75}{2.5} = 10.3$; $\frac{82.5}{2.75} = \frac{82.50}{2.75} = 30$; $\frac{7.5}{2.5} = 3$.

To carry a division to any number of decimal places. Annex ciphers to the dividend, and divide, until the desired number of figures in the quotient is reached, which are pointed off as above shown. Thus, $36.5 \div 18.1$ to three decimal places $= \frac{36.5000}{18.1} = 2.016+$. (The sign + thus placed after a number indicates that the exact result would be more than the one given if the division were carried further.)

To reduce a decimal to a common fraction. Place the decimal as the numerator; and for the denominator put 1 with as many ciphers as there are figures to the right of the decimal point; thus, .375 has three figures to the right of the point; hence, .375 in. $= \frac{375}{1000} = \frac{3}{8}$ in.

To reduce a common fraction to a decimal. Divide the numerator by the denominator, and point off as many places as there have been ciphers annexed; thus, $\frac{3}{16}$ in. = $3.0000 \div 16$ = .1875 in.

DUODECIMALS.

The duodecimal system of numerals is that in which the base is 12, instead of 10, as in the common decimal system. As a method of calculation it has fallen into almost entire disuse, and it is only in calculation of areas that duodecimals are now used. When the work becomes familiar, the work is practically as rapid as by using feet and decimals, and has the advantage of being absolutely accurate, which the decimal system is not, as inches cannot be expressed exactly in decimals of a foot. The principles upon which the work is based are as follows: When feet are multiplied by feet, or inches by inches, the product is, of course, square feet or square inches, respectively; but, when feet are multiplied by inches, or vice versa, the results may, for want of a better name, be termed *parts* (although this name was given originally to the 144th part of a square foot). Suppose a square foot to be divided into 144 sq. in.; then a strip 12 in., or 1 ft., long, and 1 in. wide will correspond to 1 part. A strip 5 ft. long and 7 in. wide will contain 7×5, or 35 parts, which, divided by 12 (parts to a square foot), equals 2 sq. ft. and 11 parts, or 2 sq. ft. + (11×12) sq. in. Square inches may be reduced to parts by dividing by 12; thus, 54 sq. in. = 4 parts 6 sq. in. To illustrate these principles, let it be required to find the area of a room 18 ft. 10 in. long, and 16 ft. 7 in. wide. Place feet under feet, and inches under inches, thus:

Feet.	*Inches.*	
18	10	
16	7	
301	4	
10	11	10
312 sq. ft.	3 parts	10 sq. in.,

or, 312 sq. ft. 46 sq. in.

Begin by multiplying 10 in. by 16 ft., which equals 160 parts, or 13 sq. ft. 4 parts. Place the 4 parts in the inches column, and carry the 13 sq. ft. Then 18 ft. $\times$ 16 ft. = 288 sq. ft. + 13 sq. ft. = 301 sq. ft. Next, multiply 10 in. by 7 in. = 70 sq. in., or 5 parts 10 sq. in. Set the 10 sq. in. to the right of the column of parts, as shown. Then, 18 ft. $\times$ 7 in. = 126 parts + 5 parts carried = 131 parts; dividing by 12, 131 parts = 10 sq. ft. 11 parts. Set these down in the proper columns and add, beginning at the right; 4 parts + 11 parts = 1 sq. ft. 3 parts. Expressed in square feet and square inches, the result is 312 sq. ft. 46 sq. in., which can be verified by reducing the given numbers to inches, multiplying them, and dividing by 144.

INVOLUTION.

Involution is the process of multiplying a number by itself one or more times, the product obtained being called a certain *power* of the number. If the number is multiplied by itself, the result is called the *square* of the number; thus, 9 is the square of 3, since $3 \times 3 = 9$. If the square of a number is multiplied by the number, the result is called the *cube* of the number; thus, 27 is the cube of 3, since $3 \times 3 \times 3 = 27$. The power to which a number is to be raised is indicated by a small figure, called an *exponent*, placed to the right and a little above the number; thus, 7^2 means that 7 is to be squared; 27^3 means that 27 is to be cubed, etc.

The operations of involution present no difficulty, as nothing but multiplication is involved, the number of times the number is to be taken as a factor being shown by the exponent.

If the number is a fraction, raise both numerator and denominator to the power indicated.

A valuable little rule to memorize for finding the square of a mixed number in which the fraction is $\frac{1}{2}$, as $3\frac{1}{2}$, $10\frac{1}{2}$, etc., is as follows: *Multiply the next less whole number by the next greater, and add* $\frac{1}{4}$. For example, the square of $6\frac{1}{2}$ is 6 (the next less number) $\times$ 7 (the next greater) $+ \frac{1}{4} = 42\frac{1}{4}$; $(19\frac{1}{2})^2 = 19 \times 20 + \frac{1}{4} = 380\frac{1}{4}$; $(8\frac{1}{2})^2 = 8 \times 9 + \frac{1}{4} = 72\frac{1}{4}$; etc.

EVOLUTION.

Evolution is the reverse of involution, and is the process of finding one of the equal factors of a number, termed a *root*, which, multiplied by itself a certain number of times, will give a product equal to the given number. When the number is to be resolved into two equal factors, either on is called the *square* root; when there are to be three equal factors, each one is called the *cube* root; etc. The operati ns to be performed are indicated by the radical sign $\sqrt{}$ and vinculum $\overline{\quad}$, and by an index figure; for square root, the index is omitted. For example, $\sqrt{64}$ is read the square root of 64 which is 8, since $8 \times 8 = 64$; $\sqrt[3]{64}$ means cube root of 64, which is 4, as $4 \times 4 \times 4 = 64$.

A number is said to be a *perfect square*, or a *perfect cube*, etc. when the root consists only of a whole number; thus, 64 is a perfect cube, since the cube root is 4, without any decimal.

SQUARE ROOT.

In extracting the square root of a number, the first step is to find how many figures there are in the root. This is done by pointing off periods of *two* figures each, beginning with the unit figure; or, if the number is partly decimal, begin at the decimal point, and point off each way. Thus, in the square root of 625 there are two figures (6′25); in 105.0625, there are four figures (1′05′.06′25) in the root.

To extract the square root, having pointed off the number into periods, proceed as follows: Let it be required to find the square root of 217. There are two figures in the whole-number part of the root; thus, 2′17. Find the number whose square is nearest in value to the first period; in this case it is 1. Divide the first period (or *trial dividend*) by twice this number (which call the *trial root*), and to the quotient add ½ the same number; thus, $\frac{2}{1 \times 2} + \frac{1}{2} = 1.5$. Disregarding the decimal point, and retaining *two* figures of the first trial root, the new trial root is 15. Add the second period of the number to the first trial dividend, and then repeat the

operations shown; thus, $\frac{2'17}{15 \times 2} + \frac{15}{2} = 7.23 + 7.5 = 14.73$, or the correct root to two decimal places. If it is desired to carry the work further, the same operations would be gone through; the next trial root would be 147 (retaining *three* figures, and increasing the last by 1 if the fourth figure is 5 or over), disregarding the decimal point; thus, $\frac{2'17'00}{147 \times 2} + \frac{147}{2}$ $= 73.809 + 73.50 = 147.309$. The position of the decimal point is found by knowing that there are two figures in the whole-number or integral part of the root, or the root is 14.7309, correct to four decimal places. For the next trial root, *four* figures (as 1,473) would be retained, and another period would be annexed to the trial dividend, etc.

The process may be remembered by help of this simple formula,

$$\text{Root} = \frac{D}{2R} + \frac{R}{2},$$

in which D is the trial dividend and R the trial root. (The method of using formulas is explained in a succeeding article.)

If the first period is a perfect square, as 1, 4, etc., use the first two periods as a trial dividend, add a cipher to the trial root, and proceed as before shown. If the number contains a decimal, pay no attention to the point till necessary to point off the result.

The following example illustrates the last named principles: What is the square root of 427.75? There are two figures in the integral part of the root; thus, 4′27. Since 4 is the square of 2, 4′27 is used as the first trial dividend, and 20 as the trial divisor; then $\frac{4'27}{20 \times 2} + \frac{20}{2} = 10.67 + 10 = 20.7$. Next, disregarding the decimal point, $\frac{4'27'75}{207 \times 2} + \frac{207}{2} = 103.3 + 103.5$ $= 206.8$. Pointing off the two figures in the integral part of the root, the root is 20.68, to two decimal places.

If a number is wholly decimal, the root will also be wholly decimal. If there are ciphers immediately following the decimal point in the number, divide the number of ciphers

by 2, and, *disregarding any remainder,* the result will be the number of ciphers between the decimal point and the first significant figure; thus, in the root of .00049, there will be 3 ciphers ÷ 2 = 1 cipher in the root, which is .022+. If there is no, or but one, cipher between the point and the first significant figure of the number, there will be none immediately after the decimal point in the root. The roots of numbers having ciphers immediately after the decimal point are found in the usual way, disregarding the ciphers (after pointing off the periods) until the position of the decimal point is to be found.

If any decimal period consists of but one figure, annex a cipher to it. Thus, $\sqrt{.5} = \sqrt{.50} = .7071$; $\sqrt{.00'00'9} = \sqrt{.00'00'90} = .0094+$.

If a number is a perfect square, it will be known by a result being obtained which is the same as the trial root used as divisor; thus, in $\sqrt{40'96}$, it will be found that the third trial root is 64, and the quotient obtained is also 64, which is, therefore, $\sqrt{4,096}$.

The square root of a fraction is found by finding the square roots of the numerator and the denominator, and dividing the former square root by the latter; thus,

$$\sqrt{\frac{9}{64}} = \frac{\sqrt{9}}{\sqrt{64}} = \frac{3}{8}; \sqrt{\frac{1}{4}} = \frac{\sqrt{1}}{\sqrt{4}} = \frac{1}{2}.$$

Otherwise, the fraction may be reduced to a decimal, and the square root of this found.

CUBE ROOT.

The first step in extracting cube root is to point off the number into periods of *three* figures each, beginning at the right, for whole numbers; begin at the decimal point if the number is partly decimal; and, if the number is wholly decimal, point off towards the right from the decimal point. The cube root of a whole number will contain as many figures as there are periods and parts of periods in the number. If the number is wholly decimal, and has less than

three ciphers between the decimal point and the first significant figure, there will be no cipher immediately after the decimal point in the root; thus, $\sqrt[3]{.125} = .5$; $\sqrt[3]{.008} = .2$. If there are ciphers immediately following the decimal point in a wholly decimal number, the number of ciphers in the root will be found by dividing the number of ciphers in the number by 3, *neglecting any remainder;* thus, in $\sqrt[3]{.000008}$ there are $\frac{5}{3} = 1$ cipher, and the root is .02. If the last period of a decimal number has less than three figures, annex enough figures to make a full period; thus, $\sqrt[3]{.3} = \sqrt[3]{.300}$.

The method of extracting cube root is quite similar to that followed for square root, and may be expressed by the formula:

$$\text{Root} = \frac{D}{3\,R^2} + \frac{2\,R}{3},$$

in which D is the trial dividend and R the trial root.

The following example shows the process in detail: What is the cube root of 20′796.875? Pointing off from the decimal point to the left, it is seen that there are two figures in the whole-number part of the root. The number whose cube is *nearest* 20 is 3; then applying the formula, since $D = 20$, and $R = 3$, the next trial root is

$$\frac{20}{3 \times 3^2} + \frac{2 \times 3}{3} = .74 + 2 = 2.74.$$

Retain two figures, increasing the second if the third is 5 or over; then the second trial root is 27. Annexing another period to the trial dividend, and repeating the above process:

$$\frac{20'796}{3 \times 27^2} + \frac{2 \times 27}{3} = 9.51 + 18 = 27.51.$$

For the third trial root, retain three figures, and as before neglect the decimal point. Annex the next period for the new trial dividend, and repeat the process; thus,

$$\frac{20'796'875}{3 \times 275^2} + \frac{2 \times 275}{3} = 91.67 + 183.33 = 275.00;$$

or, pointing off as above shown, the root is 27.5. If the operation is repeated one step further, a root is obtained which is the same as the trial root used, which result shows that the given number is a perfect cube.

If the first period is a perfect cube, use two periods as the

trial dividend, and annex a cipher to the number whose cu is equal to the first period; this number will then be the fi trial root. Thus, in $\sqrt[3]{1'728}$, the trial root will be 10, the fi approximation giving

$$\frac{1'728}{3 \times 10^2} + \frac{2 \times 10}{3} = 5.76 + 6.67 = 12.43;$$

and the operations being continued will give 12 as the exa root.

The cube root of a fraction may be found by extracti the cube root of the numerator and that of the denon nator, and dividing the former result by the latter; thus,

$$\sqrt[3]{\frac{27}{64}} = \frac{\sqrt[3]{27}}{\sqrt[3]{64}} = \frac{3}{4};\ \sqrt[3]{\frac{1}{8}} = \frac{\sqrt[3]{1}}{\sqrt[3]{8}} = \frac{1}{2}.$$

Otherwise, the fraction may be reduced to a decimal, an the cube root of this found.

The general method of extracting cube root is so similar that for extracting square root, which was quite fully show that no further explanation is necessary.

HIGHER ROOTS.

The fourth root of a number may be found by extracti the square root of the square root of the number; thus,

$$\sqrt[4]{256} = \sqrt{\sqrt{256}} = \sqrt{16} = 4.$$

The sixth root of a number may be found by extracting th square root of the cube root, or the cube root of the squa root; thus,

$$\sqrt[6]{64} = \sqrt[3]{\sqrt{64}} = \sqrt[3]{8} = 2.$$

The general formula for extracting any root is

$$\text{Root} = \frac{D}{n \times R^{n-1}} + \frac{n-1}{n} R,$$

in which n is the index of the root sought, D the trial div dend, and R the trial root. For example,

$$\text{Fourth root} = \frac{D}{4\,R^3} + \frac{3}{4} R;\ \text{fifth root} = \frac{D}{5\,R^4} + \frac{4}{5} R.$$

These roots are to be found by the same general metho explained for square and cube roots.

SQUARE ROOTS AND CUBE ROOTS.

TABLE OF SQUARE ROOTS AND CUBE ROOTS, OF NUMBERS FROM 1 TO 1,005.

NOTE.—Wherever the effect of a fourth decimal in the following roots would be to add 1 to the third and final decimal in the table, the addition has been made.

No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.
1	1.000	1.000	31	5.568	3.141	61	7.810	3.936
2	1.414	1.260	32	5.657	3.175	62	7.874	3.958
3	1.732	1.442	33	5.745	3.207	63	7.937	3.979
4	2.000	1.587	34	5.831	3.240	64	8.000	4.000
5	2.236	1.710	35	5.916	3.271	65	8.062	4.021
6	2.449	1.817	36	6.000	3.302	66	8.124	4.041
7	2.646	1.913	37	6.083	3.332	67	8.185	4.061
8	2.828	2.000	38	6.164	3.362	68	8.246	4.082
9	3.000	2.080	39	6.245	3.391	69	8.307	4.102
10	3.162	2.154	40	6.325	3.420	70	8.367	4.121
11	3.317	2.224	41	6.403	3.448	71	8.426	4.141
12	3.464	2.289	42	6.481	3.476	72	8.485	4.160
13	3.606	2.351	43	6.557	3.503	73	8.544	4.179
14	3.742	2.410	44	6.633	3.530	74	8.602	4.198
15	3.873	2.466	45	6.708	3.557	75	8.660	4.217
16	4.000	2.520	46	6.782	3.583	76	8.718	4.236
17	4.123	2.571	47	6.856	3.609	77	8.775	4.254
18	4.243	2.621	48	6.928	3.634	78	8.832	4.273
19	4.359	2.668	49	7.000	3.659	79	8.888	4.291
20	4.472	2.714	50	7.071	3.684	80	8.944	4.309
21	4.583	2.759	51	7.141	3.708	81	9.000	4.327
22	4.690	2.802	52	7.211	3.732	82	9.055	4.344
23	4.796	2.844	53	7.280	3.756	83	9.110	4.362
24	4.899	2.884	54	7.348	3.780	84	9.165	4.379
25	5.000	2.924	55	7.416	3.803	85	9.219	4.397
26	5.099	2.962	56	7.483	3.826	86	9.274	4.414
27	5.196	3.000	57	7.550	3.848	87	9.327	4.431
28	5.291	3.037	58	7.616	3.871	88	9.381	4.448
29	5.385	3.072	59	7.681	3.893	89	9.434	4.465
30	5.477	3.107	60	7.746	3.915	90	9.487	4.481

TABLE—(*Continued*).

No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.
91	9.539	4.498	131	11.445	5.079	171	13.077	5.550
92	9.592	4.514	132	11.489	5.092	172	13.115	5.561
93	9.644	4.531	133	11.533	5.104	173	13.153	5.572
94	9.695	4.547	134	11.576	5.117	174	13.191	5.583
95	9.747	4.563	135	11.619	5.130	175	13.229	5.593
96	9.798	4.579	136	11.662	5.143	176	13.266	5.604
97	9.849	4.595	137	11.705	5.155	177	13.304	5.615
98	9.899	4.610	138	11.747	5.168	178	13.342	5.625
99	9.950	4.626	139	11.790	5.180	179	13.379	5.636
100	10.000	4.642	140	11.832	5.192	180	13.416	5.646
101	10.050	4.657	141	11.874	5.205	181	13.454	5.657
102	10.099	4.672	142	11.916	5.217	182	13.491	5.667
103	10.149	4.687	143	11.958	5.229	183	13.528	5.677
104	10.198	4.703	144	12.000	5.241	184	13.565	5.688
105	10.247	4.718	145	12.042	5.254	185	13.601	5.698
106	10.296	4.733	146	12.083	5.266	186	13.638	5.708
107	10.344	4.747	147	12.124	5.278	187	13.675	5.718
108	10.392	4.762	148	12.165	5.290	188	13.711	5.729
109	10.440	4.777	149	12.207	5.301	189	13.748	5.739
110	10.488	4.791	150	12.247	5.313	190	13.784	5.749
111	10.536	4.806	151	12.288	5.325	191	13.820	5.759
112	10.583	4.820	152	12.329	5.337	192	13.856	5.769
113	10.630	4.835	153	12.369	5.348	193	13.892	5.779
114	10.677	4.849	154	12.410	5.360	194	13.928	5.789
115	10.724	4.863	155	12.450	5.372	195	13.964	5.799
116	10.770	4.877	156	12.490	5.383	196	14.000	5.809
117	10.817	4.891	157	12.530	5.395	197	14.036	5.819
118	10.863	4.905	158	12.570	5.406	198	14.071	5.828
119	10.909	4.919	159	12.609	5.417	199	14.107	5.838
120	10.954	4.932	160	12.649	5.429	200	14.142	5.848
121	11.000	4.946	161	12.689	5.440	201	14.177	5.858
122	11.045	4.960	162	12.728	5.451	202	14.213	5.867
123	11.090	4.973	163	12.767	5.463	203	14.248	5.877
124	11.135	4.987	164	12.806	5.474	204	14.283	5.887
125	11.180	5.000	165	12.845	5.485	205	14.318	5.896
126	11.225	5.013	166	12.884	5.496	206	14.353	5.906
127	11.269	5.026	167	12.923	5.507	207	14.387	5.915
128	11.314	5.040	168	12.961	5.518	208	14.422	5.925
129	11.358	5.053	169	13.000	5.529	209	14.457	5.934
130	11.402	5.066	170	13.038	5.540	210	14.491	5.944

TABLE—(*Continued*).

No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.
211	14.526	5.953	251	15.843	6.308	291	17.059	6.627
212	14.560	5.963	252	15.874	6.316	292	17.088	6.634
213	14.594	5.972	253	15.906	6.325	293	17.117	6.642
214	14.629	5.981	254	15.937	6.333	294	17.146	6.649
215	14.663	5.991	255	15.969	6.341	295	17.176	6.657
216	14.697	6.000	256	16.000	6.350	296	17.205	6.664
217	14.721	6.009	257	16.031	6.358	297	17.234	6.672
218	14.765	6.018	258	16.062	6.366	298	17.263	6.679
219	14.799	6.028	259	16.093	6.374	299	17.292	6.687
220	14.832	6.037	260	16.124	6.382	300	17.320	6.694
221	14.866	6.046	261	16.155	6.391	301	17.349	6.702
222	14.900	6.055	262	16.186	6.399	302	17.378	6.709
223	14.933	6.064	263	16.217	6.407	303	17.407	6.717
224	14.967	6.073	264	16.248	6.415	304	17.436	6.724
225	15.000	6.082	265	16.279	6.423	305	17.464	6.731
226	15.033	6.091	266	16.309	6.431	306	17.493	6.739
227	15.066	6.100	267	16.340	6.439	307	17.521	6.746
228	15.100	6.109	268	16.371	6.447	308	17.550	6.753
229	15.133	6.118	269	16.401	6.455	309	17.578	6.761
230	15.166	6.127	270	16.432	6.463	310	17.607	6.768
231	15.199	6.136	271	16.462	6.471	311	17.635	6.775
232	15.231	6.145	272	16.492	6.479	312	17.663	6.782
233	15.264	6.153	273	16.523	6.487	313	17.692	6.790
234	15.297	6.162	274	16.553	6.495	314	17.720	6.797
235	15.330	6.171	275	16.583	6.503	315	17.748	6.804
236	15.362	6.180	276	16.613	6.511	316	17.776	6.811
237	15.395	6.188	277	16.643	6.519	317	17.804	6.818
238	15.427	6.197	278	16.673	6.526	318	17.833	6.826
239	15.460	6.206	279	16.703	6.534	319	17.861	6.833
240	15.492	6.214	280	16.733	6.542	320	17.888	6.840
241	15.524	6.223	281	16.763	6.550	321	17.916	6.847
242	15.556	6.232	282	16.793	6.558	322	17.944	6.854
243	15.588	6.240	283	16.823	6.565	323	17.972	6.861
244	15.620	6.249	284	16.852	6.573	324	18.000	6.868
245	15.652	6.257	285	16.882	6.581	325	18.028	6.875
246	15.684	6.266	286	16.911	6.588	326	18.055	6.882
247	15.716	6.274	287	16.941	6.596	327	18.083	6.889
248	15.748	6.283	288	16.971	6.604	328	18.111	6.896
249	15.780	6.291	289	17.000	6.611	329	18.138	6.903
250	15.811	6.300	290	17.029	6.619	330	18.166	6.910

TABLE—(*Continued*).

No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.
331	18.193	6.917	371	19.261	7.185	411	20.273	7.435
332	18.221	6.924	372	19.287	7.192	412	20.298	7.441
333	18.248	6.931	373	19.313	7.198	413	20.322	7.447
334	18.276	6.938	374	19.339	7.205	414	20.347	7.453
335	18.303	6.945	375	19.365	7.211	415	20.371	7.459
336	18.330	6.952	376	19.391	7.218	416	20.396	7.465
337	18.358	6.959	377	19.416	7.224	417	20.421	7.471
338	18.385	6.966	378	19.442	7.230	418	20.445	7.477
339	18.412	6.973	379	19.468	7.237	419	20.469	7.483
340	18.439	6.979	380	19.494	7.243	420	20.494	7.489
341	18.466	6.986	381	19.519	7.249	421	20.518	7.495
342	18.493	6.993	382	19.545	7.256	422	20.543	7.501
343	18.520	7.000	383	19.570	7.262	423	20.567	7.507
344	18.547	7.007	384	19.596	7.268	424	20.591	7.513
345	18.574	7.014	385	19.621	7.275	425	20.615	7.518
346	18.601	7.020	386	19.647	7.281	426	20.640	7.524
347	18.628	7.027	387	19.672	7.287	427	20.664	7.530
348	18.655	7.034	388	19.698	7.294	428	20.688	7.536
349	18.681	7.041	389	19.723	7.300	429	20.712	7.542
350	18.708	7.047	390	19.748	7.306	430	20.736	7.548
351	18.735	7.054	391	19.774	7.312	431	20.760	7.554
352	18.762	7.061	392	19.799	7.319	432	20.785	7.559
353	18.788	7.067	393	19.824	7.325	433	20.809	7.565
354	18.815	7.074	394	19.849	7.331	434	20.833	7.571
355	18.841	7.081	395	19.875	7.337	435	20.857	7.577
356	18.868	7.087	396	19.900	7.343	436	20.881	7.583
357	18.894	7.094	397	19.925	7.350	437	20.904	7.589
358	18.921	7.101	398	19.950	7.356	438	20.928	7.594
359	18.947	7.107	399	19.975	7.362	439	20.952	7.600
360	18.974	7.114	400	20.000	7.368	440	20.976	7.606
361	19.000	7.120	401	20.025	7.374	441	21.000	7.612
362	19.026	7.127	402	20.050	7.380	442	21.024	7.617
363	19.053	7.133	403	20.075	7.386	443	21.048	7.623
364	19.079	7.140	404	20.100	7 392	444	21.071	7.629
365	19.105	7.147	405	20.125	7.399	445	21.095	7.635
366	19.131	7.153	406	20.149	7.405	446	21.119	7.640
367	19.157	7.160	407	20.174	7.411	447	21.142	7.646
368	19.183	7.166	408	20.199	7.417	448	21.166	7.652
369	19.209	7.173	409	20.224	7.423	449	21.190	7.657
370	19.235	7.179	410	20.248	7.429	450	21.213	7.663

TABLE—(*Continued*)..

No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.
451	21.237	7.669	491	22.158	7.889	531	23.043	8.098
452	21.260	7.674	492	22.181	7.894	532	23.065	8.103
453	21.284	7.680	493	22.204	7.900	533	23.087	8.108
454	21.307	7.686	494	22.226	7.905	534	23.108	8.113
455	21.331	7.691	495	22.249	7.910	535	23.130	8.118
456	21.354	7.697	496	22.271	7.916	536	23.152	8.123
457	21.378	7.703	497	22.293	7.921	537	23.173	8.128
458	21.401	7.708	498	22.316	7.926	538	23.195	8.133
459	21.424	7.714	499	22.338	7.932	539	23.216	8.138
460	21.448	7.719	500	22.361	7.937	540	23.238	8.143
461	21.471	7.725	501	22.383	7.942	541	23.259	8.148
462	21.494	7.731	502	22.405	7.948	542	23.281	8.153
463	21.517	7.736	503	22.428	7.953	543	23.302	8.158
464	21.541	7.742	504	22.450	7.958	544	23.324	8.163
465	21.564	7.747	505	22.472	7.963	545	23.345	8.168
466	21.587	7.753	506	22.494	7.969	546	23.367	8.173
467	21.610	7.758	507	22.517	7.974	547	23.388	8.178
468	21.633	7.764	508	22.539	7.979	548	23.409	8.183
469	21.656	7.769	509	22.561	7.984	549	23.431	8.188
470	21.679	7.775	510	22.583	7.990	550	23.452	8.193
471	21.702	7.780	511	22.605	7.995	551	23.473	8.198
472	21.726	7.786	512	22.627	8.000	552	23.495	8.203
473	21.749	7.791	513	22.649	8.005	553	23.516	8.208
474	21.771	7.797	514	22.672	8.010	554	23.537	8.213
475	21.794	7.802	515	22.694	8.016	555	23.558	8.218
476	21.817	7.808	516	22.716	8.021	556	23.580	8.223
477	21.840	7.813	517	22.738	8.026	557	23.601	8.228
478	21.863	7.819	518	22.760	8.031	558	23.622	8.233
479	21.886	7.824	519	22.782	8.036	559	23.643	8.238
480	21.909	7.830	520	22.803	8.041	560	23.664	8.243
481	21.932	7.835	521	22.825	8.047	561	23.685	8.247
482	21.954	7.841	622	22.847	8.052	562	23.706	8.252
483	21.977	7.846	523	22.869	8.057	563	23.728	8.257
484	22.000	7.851	524	22.891	8.062	564	23.749	8.262
485	22.023	7.857	525	22.913	8.067	565	23.770	8.267
486	22.045	7.862	526	22.935	8.072	566	23.791	8.272
487	22.068	7.868	527	22.956	8.077	567	23.812	8.277
488	22.091	7.873	528	22.978	8.082	568	23.833	8.282
489	22.113	7.878	529	23.000	8.088	569	23.854	8.286
490	22.136	7.884	530	23.022	8.093	570	23.875	8.291

TABLE—(*Continued*).

No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.
571	23.896	8.296	611	24.718	8.486	651	25.515	8.667
572	23.916	8.301	612	24.739	8.490	652	25.534	8.671
573	23.937	8.306	613	24.759	8.495	653	25.554	8.676
574	23.958	8.311	614	24.779	8.499	654	25.573	8.680
575	23.979	8.315	615	24.799	8.504	655	25.593	8.684
576	24.000	8.320	616	24.819	8.509	656	25.612	8.689
577	24.021	8.325	617	24.839	8.513	657	25.632	8.693
578	24.042	8.330	618	24.860	8.518	658	25.651	8.698
579	24.062	8.335	619	24.880	8.522	659	25.671	8.702
580	24.083	8.340	620	24.900	8.527	660	25.690	8.707
581	24.104	8.344	621	24.920	8.532	661	25.710	8.711
582	24.125	8.349	622	24.940	8.536	662	25.729	8.715
583	24.145	8.354	623	24.960	8.541	663	25.749	8.720
584	24.166	8.359	624	24.980	8.545	664	25.768	8.724
585	24.187	8.363	625	25.000	8.550	665	25.788	8.728
586	24.207	8.368	626	25.020	8.554	666	25.807	8.733
587	24.228	8.373	627	25.040	8.559	667	25.826	8.737
588	24.249	8.378	628	25.060	8.563	668	25.846	8.742
589	24.269	8.382	629	25.080	8.568	669	25.865	8.746
590	24.290	8.387	630	25.100	8.573	670	25.884	8.750
591	24.310	8.392	631	25.120	8.577	671	25.904	8.755
592	24.331	8.397	632	25.140	8.582	672	25.923	8.759
593	24.352	8.401	633	25.159	8.586	673	25.942	8.763
594	24.372	8.406	634	25.179	8.591	674	25.961	8.768
595	24.393	8.411	635	25.199	8.595	675	25.981	8.772
596	24.413	8.415	636	25.219	8.600	676	26.000	8.776
597	24.434	8.420	637	25.239	8.604	677	26.019	8.781
598	24.454	8.425	638	25.259	8.609	678	26.038	8.785
599	24.474	8.430	639	25.278	8.613	679	26.058	8.789
600	24.495	8.434	640	25.298	8.618	680	26.077	8.794
601	24.515	8.439	641	25.318	8.622	681	26.096	8.798
602	24.536	8.444	642	25.338	8.627	682	26.115	8.802
603	24.556	8.448	643	25.357	8.631	683	26.134	8.807
604	24.576	8.453	644	25.377	8.636	684	26.153	8.811
605	24.597	8.458	645	25.397	8.640	685	26.172	8.815
606	24.617	8.462	646	25.416	8.645	686	26.192	8.819
607	24.637	8.467	647	25.436	8.649	687	26.211	8.824
608	24.658	8.472	648	25.456	8.653	688	26.230	8.828
609	24.678	8.476	649	25.475	8.658	689	26.249	8.832
610	24.698	8.481	650	25.495	8.662	690	26.268	8.837

TABLE—(*Continued*).

No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.
691	26.287	8.841	731	27.037	9.008	771	27.767	9.170
692	26.306	8.845	732	27.055	9.012	772	27.785	9.174
693	26.325	8.849	733	27.074	9.016	773	27.803	9.177
694	26.344	8.854	734	27.092	9.020	774	27.821	9.181
695	26.363	8.858	735	27.111	9.025	775	27.839	9.185
696	26.382	8.862	736	27.129	9.029	776	27.857	9.189
697	26.401	8.866	737	27.148	9.033	777	27.875	9.193
698	26.420	8.871	738	27.166	9.037	778	27.893	9.197
699	26.439	8.875	739	27.185	9.041	779	27.911	9.201
700	26.457	8.879	740	27.203	9.045	780	27.928	9.205
701	26.476	8.883	741	27.221	9.049	781	27.946	9.209
702	26.495	8.887	742	27.240	9.053	782	27.964	9.213
703	26.514	8.892	743	27.258	9.057	783	27.982	9.217
704	26.533	8.896	744	27.276	9.061	784	28.000	9.221
705	26.552	8.900	745	27.295	9.065	785	28.018	9.225
706	26.571	8.904	746	27.313	9.069	786	28.036	9.229
707	26.589	8.908	747	27.331	9.073	787	28.053	9.233
708	26.608	8.913	748	27.350	9.077	788	28.071	9.236
709	26.627	8.917	749	27.368	9.082	789	28.089	9.240
710	26.646	8.921	750	27.386	9.086	790	28.107	9.244
711	26.665	8.925	751	27.404	9.090	791	28.125	9.248
712	26.683	8.929	752	27.423	9.094	792	28.142	9.252
713	26.702	8.934	753	27.441	9.098	793	28.160	9.256
714	26.721	8.938	754	27.459	9.102	794	28.178	9.260
715	26.739	8.942	755	27.477	9.106	795	28.196	9.264
716	26.758	8.946	756	27.495	9.110	796	28.213	9.268
717	26.777	8.950	757	27.514	9.114	797	28.231	9.272
718	26.795	8.954	758	27.532	9.118	798	28.249	9.275
719	26.814	8.959	759	27.550	9.122	799	28.267	9.279
720	26.833	8.963	760	27.568	9.126	800	28.284	9.283
721	26.851	8.967	761	27.586	9.130	801	28.302	9.287
722	26.870	8.971	762	27.604	9.134	802	28.320	9.291
723	26.889	8.975	763	27.622	9.138	803	28.337	9.295
724	26.907	8.979	764	27.640	9.142	804	28.355	9.299
725	26.926	8.983	765	27.659	9.146	805	28.372	9.302
726	26.944	8.988	766	27.677	9.150	806	28.390	9.306
727	26.963	8.992	767	27.695	9.154	807	28.408	9.310
728	26.981	8.996	768	27.713	9.158	808	28.425	9.314
729	27.000	9.000	769	27.731	9.162	809	28.443	9.318
730	27.018	9.004	770	27.749	9.166	810	28.460	9.322

TABLE—(*Continued*).

No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.
811	28.478	9.325	851	29.172	9.476	891	29.850	9.623
812	28.496	9.329	852	29.189	9.480	892	29.866	9.626
813	28.513	9.333	853	29.206	9.484	893	29.883	9.630
814	28.531	9.337	854	29.223	9.487	894	29.900	9.633
815	28.548	9.341	855	29.240	9.491	895	29.917	9.637
816	28.566	9.345	856	29.257	9.495	896	29.933	9.641
817	28.583	9.348	857	29.275	9.499	897	29.950	9.644
818	28.601	9.352	858	29.292	9.502	898	29.967	9.648
819	28.618	9.356	859	29.309	9.506	899	29.983	9.651
820	28.636	9.360	860	29.326	9.510	900	30.000	9.655
821	28.653	9.364	861	29.343	9.513	901	30.017	9.658
822	28.670	9.367	862	29.360	9.517	902	30.033	9.662
823	28.688	9.371	863	29.377	9.521	903	30.050	9.666
824	28.705	9.375	864	29.394	9.524	904	30.067	9.669
825	28.723	9.379	865	29.411	9.528	905	30.083	9.673
826	28.740	9.383	866	29.428	9.532	906	30.100	9.676
827	28.758	9.386	867	29.445	9.535	907	30.116	9.680
828	28.775	9.390	868	29.462	9.539	908	30.133	9.683
829	28.792	9.394	869	29.479	9.543	909	30.150	9.687
830	28.810	9.398	870	29.496	9.546	910	30.166	9.690
831	28.827	9.402	871	29.513	9.550	911	30.183	9.694
832	28.844	9.405	872	29.530	9.554	912	30.199	9.698
833	28.862	9.409	873	29.547	9.557	913	30.216	9.701
834	28.879	9.413	874	29.563	9.561	914	30.232	9.705
835	28.896	9.417	875	29.580	9.565	915	30.249	9.708
836	28.914	9.420	876	29.597	9.568	916	30.265	9.712
837	28.931	9.424	877	29.614	9.572	917	30.282	9.715
838	28.948	9.428	878	29.631	9.576	918	30.298	9.719
839	28.965	9.432	879	29.648	9.579	919	30.315	9.722
840	28.983	9.435	880	29.665	9.583	920	30.331	9.726
841	29.000	9.439	881	29.682	9.586	921	30.348	9.729
842	29.017	9.443	882	29.698	9.590	922	30.364	9.733
843	29.034	9.447	883	29.715	9.594	923	30.381	9.736
844	29.052	9.450	884	29.732	9.597	924	30.397	9.740
845	29.069	9.454	885	29.749	9.601	925	30.414	9.743
846	29.086	9.458	886	29.766	9.605	926	30.430	9.747
847	29.103	9.461	887	29.782	9.608	927	30.447	9.750
848	29.120	9.465	888	29.799	9.612	928	30.463	9.754
849	29.138	9.469	889	29.816	9.615	929	30.479	9.757
850	29.155	9.473	890	29.833	9.619	930	30.496	9.761

TABLE—(*Continued*).

No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.	No.	Sq. Rt.	C. Rt.
931	30.512	9.764	956	30.919	9.851	981	31.321	9.936
932	30.529	9.768	957	30.935	9.855	982	31.337	9.940
933	30.545	9.771	958	30.952	9.858	983	31.353	9.943
934	30.561	9.775	959	30.968	9.861	984	31.369	9.946
935	30.578	9 778	960	30.984	9.865	985	31.385	9.950
936	30.594	9.782	961	31.000	9.868	986	31.401	9.953
937	30.610	9.785	962	31.016	9.872	987	31.417	9.956
938	30.627	9.789	963	31.032	9.875	988	31.432	9.960
939	30.643	9.792	964	31.048	9.878	989	31.448	9.963
940	30.659	9.796	965	31.064	9.882	990	31.464	9.967
941	30.676	9.799	966	31.080	9.885	991	31.480	9.970
942	30.692	9.803	967	31.097	9.889	992	31.496	9.973
943	30.708	9.806	968	31.113	9.892	993	31.512	9.977
944	30.725	9.810	969	31.129	9.896	994	31.528	9.980
945	30.741	9.813	970	31.145	9.899	995	31.544	9.983
946	30.757	9.817	971	31.161	9.902	996	31.559	9.987
947	30.773	9.820	972	31.177	9.906	997	31.575	9.990
948	30.790	9.824	973	31.193	9.909	998	31.591	9.993
949	30.806	9.827	974	31.209	9.913	999	31.607	9.997
950	30.822	9.830	975	31.225	9.916	1000	31.623	10.000
951	30.838	9.834	976	31.241	9.919	1001	31.639	10.003
952	30.854	9.837	977	31.257	9.923	1002	31.654	10.006
953	30.871	9.841	978	31.273	9.926	1003	31.670	10.010
954	30.887	9.844	979	31.289	9.929	1004	31.686	10.013
955	30.903	9.848	980	31.305	9.933	1005	31.702	10.017

The square root of any number from .01 to 10.05, advancing by .01, may be found by moving the decimal place in the Sq. Rt. column one place to the left; thus, $\sqrt{9.48} = 3.079$. The cube root of any number from .001 to 1.005, advancing by .001, may be found by moving the decimal point in the C. Rt. column one place to the left; thus, $\sqrt[3]{.816} = .9345$.

The approximate squares of numbers from 1 to 31.7, and cubes from 1 to 10, may be found, also. Required, the square of 30.53: In the Sq. Rt. column, find 30.529; 932 is, then, the approximate square of 30.53. Required, the cube of 9.8: Find in the C. Rt. column 9.799; then, the approximate cube is 941.

WEIGHTS AND MEASURES.

LINEAR MEASURE.

12	inches (in.)	=	1 foot	ft.
3	feet	=	1 yard	yd.
5.5	yards	=	1 rod	rd.
40	rods	=	1 furlong	fur.
8	furlongs	=	1 mile	mi.

in.		ft.		yd.		rd.		fur.		mi.
36	=	3	=	1						
198	=	16.5	=	5.5	=	1				
7,920	=	660	=	220	=	40	=	1		
63,360	=	5,280	=	1,760	=	320	=	8	=	1

SURVEYOR'S MEASURE.

7.92	inches	=	1 link	li.
25	links	=	1 rod	rd.
4 rods 100 links 66 feet		=	1 chain	ch.
80	chains	=	1 mile	mi.

1 mi. = 80 ch. = 320 rd. = 8,000 li. = 63,360 in.

SQUARE MEASURE.

144	square inches (sq. in.)	=	1 square foot	sq. ft.
9	square feet	=	1 square yard	sq. yd.
$30\frac{1}{4}$	square yards	=	1 square rod	sq. rd.
160	square rods	=	1 acre	A.
640	acres	=	1 square mile	sq. mi.

sq. mi.		A.		sq. rd.		sq. yd.		sq. ft.		sq. in.
1	=	640	=	102,400	=	3,097,600	=	27,878,400	=	4,014,489,600

SURVEYOR'S SQUARE MEASURE.

625 square links (sq. li.)	= 1 square rod	sq. rd.
16 square rods	= 1 square chain	sq. ch.
10 square chains	= 1 acre	A.
640 acres	= 1 square mile	sq. mi.
36 square miles (6 mi. square)	= 1 township	Tp.

1 sq. mi. = 640 A. = 6,400 sq. ch. = 102,400 sq. rd.
= 64,000,000 sq. li.

The acre contains 4,840 sq. yd., or 43,560 sq. ft., and in form of a square is 208.71 ft. on a side.

CUBIC MEASURE.

1,728 cubic inches (cu. in.)	= 1 cubic foot	cu. ft.
27 cubic feet	= 1 cubic yard	cu. yd.
128 cubic feet	= 1 cord	cd.
$24\frac{3}{4}$ cubic feet	= 1 perch	P.

1 cu. yd. = 27 cu. ft. = 46,656 cu. in.

MEASURE OF ANGLES OR ARCS.

60 seconds (″)	= 1 minute	′
60 minutes	= 1 degree	°
90 degrees	= 1 rt. angle or quadrant	□
360 degrees	= 1 circle	cir.

1 cir. = 360° = 21,600′ = 1,296,000″

AVOIRDUPOIS WEIGHT.

437.5 grains (gr.)	= 1 ounce	oz.
16 ounces	= 1 pound	lb.
100 pounds	= 1 hundredweight	cwt.
20 cwt., or 2,000 lb.	= 1 ton	T.

1 T. = 20 cwt. = 2,000 lb. = 32,000 oz. = 14,000,000 gr.

The avoirdupois pound contains 7,000 grains.

LONG TON TABLE.

16 ounces	= 1 pound	lb.
112 pounds	= 1 hundredweight	cwt.
20 cwt., or 2,240 lb.	= 1 ton	T.

TROY WEIGHT.

24 grains (gr.)	= 1	pennyweight	pwt.
20 pennyweights	= 1	ounce	oz.
12 ounces	= 1	pound	lb.

1 lb. = 12 oz. = 240 pwt. = 5,760 gr.

DRY MEASURE.

2 pints (pt.)	= 1	quart	qt.
8 quarts	= 1	peck	pk.
4 pecks	= 1	bushel	bu

1 bu. = 4 pk. = 32 qt.= 64 pt.

The U. S. struck bushel contains 2,150.42 cu. in. = 1.2444 cu. ft. Its dimensions are, by law, $18\frac{1}{2}$ in. in diameter and 8 in. deep. The heaped bushel is equal to $1\frac{1}{4}$ struck bushels, the cone being 6 in. high. The dry gallon contains 268.8 cu. in., being $\frac{1}{8}$ bu.

For approximations, the bushel may be taken at $1\frac{1}{4}$ cu. ft.; or a cubic foot may be considered $\frac{4}{5}$ of a bushel.

The British bushel contains 2,218.19 cu. in. = 1.2837 cu. ft. = 1.032 U. S. bushels.

LIQUID MEASURE.

4 gills (gi.)	= 1	pint	pt.
2 pints	= 1	quart	qt.
4 quarts	= 1	gallon	gal.
$31\frac{1}{2}$ gallons	= 1	barrel	bbl.
2 barrels, or 63 gallons	= 1	hogshead	hhd.

1 hhd. = 2 bbl. = 63 gal. = 252 qt. = 504 pt. = 2,016 gi.

The U. S. gallon contains 231 cu. in. = .134 cu. ft., nearly; or 1 cu. ft. contains 7.480 gal. The following cylinders contain the given measures very closely:

	Diam.	Height		Diam.	Height
Gill	$1\frac{3}{4}$ in.	3 in.	Gallon	7 in.	6 in.
Pint	$3\frac{1}{2}$ in.	3 in.	8 gallons	14 in.	12 in.
Quart	$3\frac{1}{2}$ in.	6 in.	10 gallons	14 in.	15 in.

With water at its maximum density (weighing 62.425 lb. per cu. ft.), a gallon of pure water weighs 8.345 lb.

For approximations, 1 cu. ft. of water is considered equal to $7\frac{1}{2}$ gal., and 1 gal. as weighing $8\frac{1}{3}$ lb.

The British imperial gallon, both liquid and dry, contains 277.274 cu. in. = .16046 cu. ft., and is equivalent to the volume of 10 lb. of pure water at 62° F. To reduce U. S. to British liquid gallons, divide by 1.2. Conversely, to convert British into U. S. liquid gallons, multiply by 1.2; or, increase the number of gallons $\frac{1}{5}$.

MISCELLANEOUS TABLE.

12 articles	=	1 dozen.	20 quires	=	1 ream.
12 dozen	=	1 gross.	1 league	=	3 miles.
12 gross	=	1 great gross.	1 fathom	=	6 feet.
2 articles	=	1 pair.	1 hand	=	4 inches.
20 articles	=	1 score.	1 palm	=	3 inches.
24 sheets	=	1 quire.	1 span	=	9 inches.

1 knot (U. S.) = 6,086.07 ft. = $1\frac{1}{6}$ miles (roughly).

1 meter = 3 feet $3\frac{3}{8}$ inches (nearly).

THE METRIC SYSTEM.

The metric system is based on the meter, which, according to the U. S. Coast and Geodetic Survey Report of 1884, is equal to 39.370432 inches. The value commonly used is 39.37 inches, and is authorized by the U. S. government. The meter is defined as one ten-millionth the distance from the pole to the equator, measured on a meridian passing near Paris.

There are three principal units—the meter, the liter (pronounced lee-ter), and the gram, the units of length, capacity, and weight, respectively. Multiples of these units are obtained by prefixing to the names of the principal units the Greek words deca (10), hecto (100), and kilo (1,000); the submultiples, or divisions, are obtained by prefixing the Latin words deci ($\frac{1}{10}$), centi ($\frac{1}{100}$), and milli ($\frac{1}{1000}$). These prefixes form the key to the entire system. In the following tables, the abbreviations of the principal units of these submultiples begin with a small letter, while those of the multiples begin with a capital letter; they should always be written as here printed.

MEASURES OF LENGTH.

Name.		*Meters.*		*U. S. In.*		*Feet.*
Millimeter (mm.)	=	.001	=	.039370	=	.003281
Centimeter (cm.)	=	.010	=	.393704	=	.032809
Decimeter (dm.)	=	.100	=	3.937043	=	.328087
Meter (m.)	=	1.000	=	39.370432	=	3.280869
Decameter (Dm.)	=	10.000			=	32.808690
Hectometer (Hm.)	=	100.000			=	328.086900
Kilometer (Km.)	=	1,000.000	=	.621 mi.	=	3,280.869000
Myriameter (Mm.)	=	10,000.000	=	6.214 mi.	=	32,808.690000

The centimeter, meter, and kilometer are the units in practical use, and may be said to occupy the same position in the metric system as do inches, yards, and miles in the U. S. and English system of measurement.

MEASURES OF AREA.

Name.	*Sq. Met.*	*Sq. In.*	*Sq. Ft.*	*Acres.*
Sq. millimeter ($mm.^2$)	= .0000010	= .001550		
Sq. centimeter ($cm.^2$)	= .0001000	= .155003	= .00107641	
Sq. decimeter ($dm.^2$)	= .0100000	= 15.5003	= .10764100	
Sq. meter, or centare ($m.^2$, or ca.)	= 1.000000	= 1,550.03	= 10.764100	= .000247
Sq. decameter, or are ($Dm.^2$, or A.)	= 100.0000	= 155,003	= 1,076.4101	= .024710
Hectare	= 10,000.00		= 107,641.01	= 2.47110
Sq. kilometer	= .3861099 sq. mi.		= 10,764,101	= 247.110
Sq. myriameter	= 38.61090 sq. mi.			= 24,711.0

MEASURES OF VOLUME.

Name.	*Cu. Met.*	*Cu. In.*	*Cu. Ft.*	*Cu. Yd.*
Cu. centimeter ($cm.^3$)	= .000001	= .061025		
Cu. decimeter ($dm.^3$)	= .001000	= 61.0254		
Centistere	= .010000	= 610.2540	= .35316	
Decistere	= .100000		= 3.53156	
Stere [= cu.m. ($m.^3$)]	= 1.000000		= 35.3156	= 1.308
Decastere	= 10.000000		= 353.156	= 13.080

MEASURES OF CAPACITY.

Name.	*Liters.*	*Liq. Meas.*	*Dry Meas.*
Milliliter (ml.) (=cu. centimeter)	= .00100 =	.008454 gill	= .001816 pint
Centiliter (cl.)	= .01000 =	.084537 gill	= .018162 pint
Deciliter (dl.)	= .10000 =	.845370 gill	= .18162 pint
Liter (l.) (= cubic decimeter)	= 1.0000 =	1.05671 qt. .264179 gal.	= .11351 peck
Decaliter (Dl.) (= centistere)	= 10.000 =	2.64179 gal.	= 1.1351 peck
Hectoliter (Hl.) (= decistere)	= 100.00 =	26.4179 gal.	= 2.83783 bu.
Kiloliter (Kl.) (= cu. m., or stere)	= 1,000.0 =	264.179 gal.	= 28.3783 bu.
Myrialiter (Ml.) (= decastere)	= 10,000 =	2641.79 gal.	= 283.783 bu.

The milliliter (or cubic centimeter) and the liter are the units most commonly used. A liter of pure water at 4° C., or 39.2° F., weighs 1 kilogram.

METRIC WEIGHTS.

The gram is the basis of metric weights, and is the weight of a cubic centimeter of distilled water at its maximum density, at sea level, Paris, barometer 29.922 inches.

Name.	*Grams.*	*Grains.*	*Av. Oz.*	*Av. Lb.*
Milligram (mg.) =	.001 =	.01543		
Centigram (cg.) =	.010 =	.15432		
Decigram (dg.) =	.100 =	1.54323		
Gram (g.) =	1.000 =	15.43235 =	.03527 =	.0022046
Decagram (Dg.) =	10.000		= .35274 =	.0220462
Hectogr'm (Hg) =	100.000		= 3.52739 =	.2204622
Kilogram (Kg.) =	1,000.000		= 35.27395 =	2.2046223
Myriogr'm (Mg) =	10,000.000		=	22.0462234
Quintal (Q.) =	100,000.000		=	220.4622341
Tonneau (T.) =	1,000,000.000		=	2,204.6223410

The gram and the kilogram (called *kilo*) are the units in common use.

FACTORS FOR CONVERSION.

For approximations, it may be useful to remember the following:

1 centimeter	=	.4 in. (nearly).
1 meter	=	40 in. (roughly).
1 kilometer	=	$\frac{5}{8}$ mile (nearly).
1 liter	=	1 liquid quart (nearly).
1 liter	=	$\frac{1}{8}$ peck (nearly).
1 gram	=	15.4 grains.
1 kilogram	=	$2\frac{1}{5}$ pounds.

To convert metric measures into U. S. measures, by use of the preceding tables, find the desired equivalent in U. S. measure of a metric unit of the denomination given, and *multiply* this equivalent by the metric number. For example, it is desired to find the equivalent in pounds of 19.6 kilos. From the table of weights, 1 kilo = 2.2046 lb.; hence, 19.6 kilos = 2.2046 × 19.6 = 43.21 lb. In similar manner, 8 liters expressed in U. S. gallons = .264179 × 8 = 2.113432 gal.

To convert U. S. measures into metric measures, find how much a metric unit of the desired denomination is equal to in U. S. measure, and *divide* the given number by this equivalent. For example, it is desired to convert $4\frac{1}{2}$ miles into kilometers. From the table of lengths, it is found that a kilometer is .621 mi.; hence, dividing 4.5 by .621, the result is 7.24 kilometers.

Other useful conversion factors are as follows:

Length.—1 in. = .0254 meter; 1 ft. = .3048 meter; 1 yd. = .9144 meter; 1 mi. = 1,609.34 meters = 1.609 kilometers.

Area.—1 sq. in. = .000645 square meter; 1 sq. ft. = .0929 square meter; 1 sq. yd. = .836 square meter; 1 acre = 4,047 square meters.

Capacity.—1 cu. in. = .0164 liter; 1 U. S. bushel = 35.24 liters; 1 U. S. dry quart = 1.101 liters; 1 U. S. peck = 8.81 liters; 1 cu. yd. = 765 liters; 1 U. S. liquid quart = .9463 liters; 1 U. S. gallon = 3.785 liters.

Weight.—1 grain = .0648 gram; 1 avoirdupois ounce = 28.349 grams; 1 Troy ounce = 31.103 grams; 1 avoirdupois pound = 453.59 grams.

SPECIFIC GRAVITIES AND WEIGHTS.

The specific gravity of a solid or liquid body is the ratio between its weight and that of a like volume of distilled water. If the solid is of irregular shape, its specific gravity may be found by weighing it in air and in water; the loss of weight in water is the weight of an equal volume of water; hence, if W is the weight in air, and W' the weight in water, the specific gravity is $\frac{W}{W - W'}$.

The weight of water in various conditions is as follows:

Water, pure at 32° F.	weighs	62.417 lb. per cu. ft.
Water, pure at 39° F.	weighs	62.425 lb. per cu. ft.
Water, pure at 62° F.	weighs	62.355 lb. per cu. ft.
Water, pure at 212° F.	weighs	59.700 lb. per cu. ft.
Water, sea	weighs	64.080 lb. per cu. ft.
Ice	weighs	57.400 lb. per cu. ft.
Snow, fresh	weighs	5 to 12 lb. per cu. ft.
Snow, wet	weighs	15 to 50 lb. per cu. ft.

METALS.

Name of Metal.	Weight per Cu. In. Pounds.	Weight per Cu. Ft. Pounds.	Specific Gravity.
Aluminum	.096	166	2.66
Antimony	.242	418	6.70
Bismuth	.350	607	9.74
Brass, cast	.292	504	8.10
Brass, rolled	.303	524	8.40
Bronze (gun metal)	.305	529	8.50
Copper, cast	.314	542	8.70
Copper, rolled	.321	555	8.90
Gold, 24 carat	.694	1,204	19.26
Iron, cast	.260	450	7.21
Iron, wrought	.277	480	7.66
Lead, commercial	.410	710	11.38
Mercury, 60° F.	.489	846	13.58
Platinum	.779	1,342	21.50
Silver	.378	655	10.50
Steel	.283	490	7.85
Tin, cast	.265	459	7.35
Zinc	.253	437	7.00

Building Materials, Etc.

Name of Material.	Weight per Cu. Ft. Pounds.	Specific Gravity.
Bluestone	160	2.56
Brick, pressed	150	2.40
Brick, common	125	2.00
Chalk	156	2.50
Charcoal	15–30	.24–.48
Clay, compact	119	1.90
Coke, loose	23–32	.37–.51
Coal, hard, solid	93.5	1.50
Coal, hard, broken	54	.865
Coal, soft, solid	84	1.35
Coal, soft, broken	50	.80
Concrete, cement	140	2.25
Cement, Portland	80–100	1.40
Cement, Rosendale	56	.89
Earth, dry, shaken	82–92	1.36
Earth, rammed	90–100	1.52
Earth, moist, shaken	75–100	1.31
Glass, average	186	2.98
Glass, common window	157	2.52
Granite	170	2.72
Gravel (see sand)		
Limestones and marbles	168	2.70
Lime, quick	53	.85
Marble (see limestone)		
Plaster of Paris	141.6	2.27
Porphyry	170.0	2.73
Quartz	165	2.65
Sand	90–106	2.65
Sandstone	151	2.41
Shales	162	2.60
Slate	175	2.80
Trap rock	187	3.00
Masonry.		
Common brickwork, cement mortar	130	2.10
Common brickwork, lime mortar	120	1.90
Granite or limestone rubble, dry	138	2.21
Granite or limestone rubble	154	2.45
Granite or limestone, well dressed	165	2.65
Mortar, hardened	103	1.65
Pressed brickwork	140	2.25
Sandstone rubble	145	2.32

WOODS (DRY).

Name of Material.	Weight per Foot. B. M.	Weight per Cu. Ft. Pounds.	Specific Gravity.
Ash	3.9	47.0	.752
Ash, American white	3.2	38.0	.610
Boxwood	5.0	60.0	.960
Cherry	3.5	42.0	.672
Chestnut	3.4	41.0	.660
Cork	1.3	15.6	.250
Elm	2.9	35.0	.560
Ebony	6.3	76.1	1.220
Hemlock	2.1	25.0	.400
Hickory	4.4	53.0	.850
Lignum vitæ	6.9	83.0	1.330
Mahogany, Spanish	4.4	53.0	.850
Mahogany, Honduras	2.9	35.0	.560
Maple	4.1	49.0	.790
Oak, live	4.9	59.3	.950
Oak, white	4.0	48.0	.770
Oak, red	3.3	40.0	.640
Pine, white	2.1	25.0	.400
Pine, yellow	2.8	34.3	.550
Pine, Southern	3.7	45.0	.720
Sycamore	3.1	37.0	.590
Spruce	2.1	25.0	.400
Walnut	3.2	38.0	.610

FORMULAS.

Formulas are simply short methods of indicating operations otherwise expressed by rules, by using letters and signs in place of words. The letters are usually those of the English alphabet, and the signs are those previously given. Besides showing at a glance the various steps, formulas are much more convenient than rules to memorize. Many people are unnecessarily deterred from using a formula, because a few letters are used instead of many words; but a formula can really be more readily followed than a rule. We

shall confine our attention to explanations of some simple formulas, and to showing how a formula may be transposed so as to obtain any required term.

To show the similarity between a rule and a formula, let it be required to find the area of footing necessary to sustain a certain load, having given the safe load per square foot. The rule is: *Divide the total load in pounds by the safe load in pounds per square foot; the quotient is the required area in square feet.* Not much space can be saved by expressing such a simple rule in a formula, but the operation is more quickly comprehended. Let the total load in pounds be represented by the letter P, the safe load per square foot by the letter S, and the required area by the letter A. Then the rule is expressed by the formula $A = \frac{P}{S}$

A formula is used by substituting for the letters the quantities known in the problem, and finding the unknown by performing the indicated operations. Sometimes the formula as written does not give the desired quantity directly, but must be rearranged so as to enable it to be found. This is done by simple operations, the aim being to obtain the desired quantity by itself on one side of the equality sign. Thus, in the above formula, suppose it is desired to find the value of P, A and S being given. By multiplying A and $\frac{P}{S}$ by S (such operation being called *clearing of fractions*) there results $A \times S = P$, in which the desired quantity P is by itself and is found to be equal to the product of A and S. The formula is further shortened by omitting the $\times$ sign, and writing $A\,S = P$. When two or more letters are thus written, it means that they are to be multiplied together. In a similar manner, S may be obtained, by dividing the last found formula through by A; thus, $S = \frac{P}{A}$.

Example.—The safe bearing power of a soil is 1,500 lb. per sq. ft. What area of footing is required to sustain a load of 30,000 lb.?

Here A is wanted, and P and S are given. Hence, $A = \frac{P}{S}$

$= \frac{30,000}{1,500} = 20$ sq. ft. Again, suppose it was desired to ascertain how much per sq. ft. a footing 20 ft. in area carried, the total load, 30,000 lb., being known. Then, A and P are given to find S; or $S = \frac{P}{A} = \frac{30,000}{20} = 1,500$ lb.

The following formula shows how to determine the safe load that a stone beam or lintel will carry, if uniformly loaded:

$$\frac{2\,b\,d^2\,A}{f\,L} = W,$$

in which
b = breadth in inches;
d = depth in inches;
A = number from a table;
f = factor of safety;
L = length in feet;
W = safe distributed load, in pounds.

Suppose any other quantity than W is wanted; it may be found by transposing the formula; thus, if the depth to sustain a certain load is required, the formula is thus arranged: Multiplying through by $f\,L$,

$$2\,b\,d^2\,A = W\,f\,L.$$

Arranging so as to have d^2 alone on one side of the = sign,

$$d^2 = \frac{W\,f\,L}{2\,b\,A}.$$

Extracting the square root,

$$d = \sqrt{\frac{W\,f\,L}{2\,b\,A}}.$$

Example.—It is desired to carry a distributed load of 3,840 lb. on a piece of bluestone flagging 4 ft. wide and 6 ft. span, using a factor of safety of 10. How thick must the stone beam be? Here, $W = 3,840$ lb.; $b = 4$ ft. $\times 12 = 48$ in.; $L = 6$ ft.; $f = 10$; A is found from a table to be 150 for bluestone; then d is the required term. Substituting the values, there results

$$d = \sqrt{\frac{3,840 \times 10 \times 6}{2 \times 48 \times 150}} = \sqrt{16} = 4 \text{ in.}$$

A rule for finding the strength of a wooden column is: *From the ultimate compressive strength of the material in pounds per square inch, subtract the fraction: the ultimate strength*

multiplied by the length of column in inches, and divided by 100 times the least side in inches. The difference is the ultimate strength of the column in pounds per square inch. This rule is rendered much more intelligible by using a formula; thus:

Let S = ultimate strength of column in lb. per sq. in.;
U = ultimate compressive strength of material in lb. per sq. in.;
l = length of column, in inches;
d = least side of column, in inches.

Then,
$$S = U - \frac{Ul}{100\,d}.$$

The values of U for different woods are found in tables.

EXAMPLE.—The ultimate compressive stress of white pine, parallel to the grain, is 3,500 lb. per sq. in. What is the ultimate load a 10″ × 10″ column 20 ft. long will carry?

Looking through the problem, it is found that all the quantities in the formula are given except S; the length expressed in inches = 240 in.; and the least side is 10 in., as the column is square. Substituting these values in the formula

$$S = U - \frac{Ul}{100\,d},$$

$$S = 3{,}500 - \frac{3{,}500 \times 240}{100 \times 10} = 3{,}500 - 840 = 2{,}660 \text{ lb.}$$

Suppose it is desired to find the side of a square wooden column to carry a known load. The preceding formula contains the required term d, but as it also involves S, which depends on d, that term must be eliminated. Let P represent the total load on the column; then, since the sectional area is d^2, $P = d^2 S$; or, substituting for S its value,

$$P = d^2\left(U - \frac{U\,l}{100\,d}\right) = d^2\,U - \frac{d\,U\,l}{100}.$$

Multiplying by 100 and dividing by U,

$$\frac{100\,P}{U} = 100\,d^2 - d\,l.$$

Such a quantity must be added to both sides of this equation (so as not to change its value) as will make the right side a perfect square. This quantity is found by trial to be $\frac{l^2}{400}$.

Then, $\frac{100\,P}{U} + \frac{l^2}{400} = 100\,d^2 - d\,l + \frac{l^2}{400}$, or $\left(10\,d - \frac{l}{20}\right)^2$.

Extracting the square root of both members, placing $\frac{l}{20}$ on the left of the equality sign, and dividing by 10,

$$\sqrt{\frac{100\,P}{U}+\frac{l^2}{400}} = 10\,d - \frac{l}{20}; \text{ and } \frac{1}{10}\sqrt{\frac{100\,P}{U}+\frac{l^2}{400}}+\frac{l}{200} = d.$$

$\frac{1}{10} = \sqrt{\frac{1}{100}}$; multiplying the expression under the radical by it,

$$\sqrt{\frac{P}{U}+\frac{l^2}{40{,}000}}+\frac{l}{200} = d.*$$

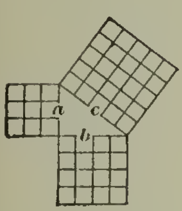
In using any formula, care must be taken to have all dimensions, weights, etc. expressed in the units required by the formula.

MENSURATION.

LINES AND PLANE SURFACES.

TRIANGLE.

Right Triangle.



Hypotenuse $c = \sqrt{a^2 + b^2}$.

Side $a = \sqrt{c^2 - b^2}$.

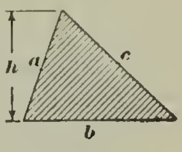
Side $b = \sqrt{c^2 - a^2}$.

Area $= \frac{1}{2}\,a\,b$.

Oblique Triangle.

If altitude or height h and base b are known:

Area $= \frac{1}{2}\,b\,h$.



If the three sides are known:

Let $s = \frac{1}{2}(a + b + c)$.

Area $= \sqrt{s(s-a)(s-b)(s-c)}$.

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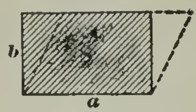
* This formula, while given as an exercise in formulas, is also useful in calculating directly the size of a square wooden column, instead of ascertaining it by trial, as is usual.

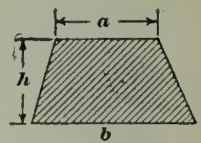


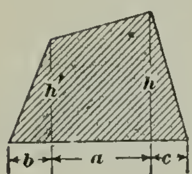
PARALLELOGRAM.

Area $= a b$.

TRAPEZOID.

Area $= \frac{1}{2} h(a + b)$.





TRAPEZIUM.

Divide into two triangles and a trapezoid.

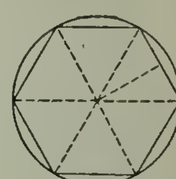
Area $= \frac{1}{2} b h' + \frac{1}{2} a(h' + h) + \frac{1}{2} c h$;

or, area $= \frac{1}{2}[b h' + c h + a(h' + h)]$.

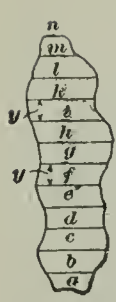
REGULAR POLYGONS.

Divide the polygon into equal triangles and find the sum of the partial areas. Otherwise, square the length of one side and multiply by proper number from the following table:

Name.	No. Sides.	Multiplier.
Triangle	3	.433
Square	4	1.000
Pentagon	5	1.720
Hexagon	6	2.598
Heptagon	7	3.634
Octagon	8	4.828
Nonagon	9	6.182
Decagon	10	7.694



IRREGULAR AREAS.



Divide the area into trapezoids, triangles, parts of circles, etc., and find the sum of the partial areas.

If the figure is very irregular, the approximate area may be found as follows: Divide the figure into trapezoids by equidistant parallel lines b, c, d, etc. The lengths of these lines being measured, then, calling a the first and n the last length, and y the width of strips,

$$\text{Area} = y\left(\frac{a + n}{2} + b + c + \text{etc.} + m\right).$$

CIRCLE.

A = area.

$\pi\ (pi) = 3.1416.$

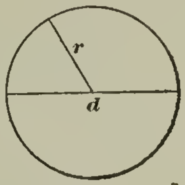
$\frac{\pi}{4} = .7854.$

p = perimeter or circumference.

$p = \pi d = 3.1416\, d.$

$p = 3\frac{1}{7}\, d$ (approximately).

$p = 2\pi r = 6.2832\, r.$



$d = \frac{p}{\pi} = \frac{p}{3.1416}.$

$d = \frac{7}{22}\, p$ (approximately).

$d = 1.128\sqrt{A}.$

$r = \frac{p}{2\pi} = \frac{p}{6.2832}.$

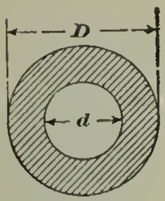
$r = .5642\sqrt{A}.$

$A = \frac{\pi d^2}{4} = .7854\, d^2.$

$A = \pi r^2 = 3.1416\, r^2.$

Side of square of area equal to circle $= .8862\, d.$

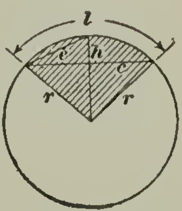
Diameter of circle of area equal to a given square $= 1.128 \times$ side.



RING.

Area $= .7854(D^2 - d^2).$

SECTOR.



If radius r and rise h are known, chord $c = 2\sqrt{2hr - h^2}.$

If chord c and rise h are known,

$$\text{radius } r = \frac{c^2 + 4h^2}{8h}.$$

Approximately, $r = \frac{c^2}{8h}.$

Subchord $e = \frac{1}{2}\sqrt{c^2 + 4h^2}.$

If h is not more than .4 c, length of arc $l = \frac{8e-c}{3}$, nearly.

If l and r are known,

$$\text{Angle } E^* = 57.296\frac{l}{r},$$

$$= 57.3\frac{l}{r}, \text{ nearly.}$$

$$\text{Area} = \tfrac{1}{2} l r.$$

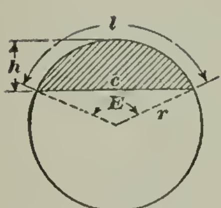
If r and angle E^* are known,

$$\text{length } l = \frac{E r}{57.296} = \frac{E r}{57.3}, \text{ nearly.}$$

$$= .0175\, E r.$$

$$\text{Area} = .0087\, r^2 E.$$

SEGMENT.



Area of segment = area of sector — area of triangle.

Height of triangle $= r - h$.

If l, r, c, and h are known,

$$\text{Area} = \tfrac{1}{2} l r - \tfrac{1}{2} c\,(r - h).$$

If c, h, r, and E are known, find l as shown under *Sector;* the area may then be found by the preceding formula.

ELLIPSE.

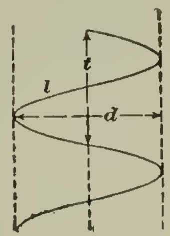
$$\dagger p = \pi\sqrt{\frac{D^2 + d^2}{2} - \frac{(D-d)^2}{8.8}},$$

$$\text{Area} = .7854\, D d.$$

*If the angle E contains minutes and seconds, these must be expressed in decimals of a degree. Divide the minutes by 60, and the seconds (if any) by 3,600, and add the sum of the decimals to the degrees; thus, $30° 45' 36'' = 30° + \frac{45}{60} + \frac{36}{3600} = 30.76°$. If E is given in degrees and decimals, it may be reduced to minutes and seconds thus, $.76° = .76° \times 60' = 45.6'$; $.6' \times 60'' = 36''$; hence, $30.76° = 30° 45' 36''$.

† The perimeter of an ellipse cannot be exactly determined, and this formula is merely an approximation giving fairly close results.

HELIX.



d = diameter of helix;
l = length of 1 turn of helix;
t = pitch, or rise in 1 turn;
n = number of turns;
$\pi^2 = 9.8696$.

$$l = \sqrt{\pi^2 d^2 + t^2}.$$

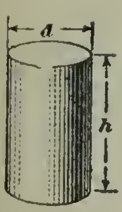
$$t = \sqrt{l^2 - \pi^2 d^2}.$$

$$\text{Total length} = n\,l = n\sqrt{\pi^2 d^2 + t^2}.$$

SOLIDS AND CURVED SURFACES.

C = convex surface;
S = whole surface;
= C + area of end or ends;
A = area larger base or end;
a = area smaller base or end;
P = perimeter of larger base;
p = perimeter of smaller base;
D = larger diameter;
d = smaller diameter;
V = volume of solid.

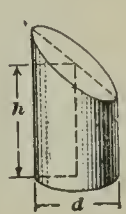
In a cylinder or prism,
$A = a$, $P = p$, and $D = d$.



CYLINDER.

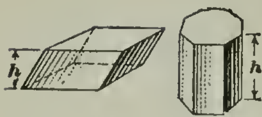
$$C = Ph = 3.1416\,d\,h;$$
$$S = 3.1416\,d\,h + 1.5708\,d^2;$$
$$V = A\,h = .7854\,d^2\,h.$$

FRUSTUM OF CYLINDER.



$h = \frac{1}{2}$ sum of greatest and least heights;
$C = Ph = 3.1416\,d\,h$;
$S = 3.1416\,d\,h + .7854\,d^2$ + area of elliptical top;
$V = A\,h = .7854\,d^2\,h$.

PRISM OR PARALLELOPIPED.

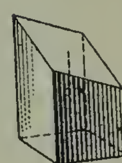


$$C = Ph;$$
$$S = Ph + 2A;$$
$$V = Ah.$$

For prisms with regular polygon as bases, P = length of one side $\times$ number of sides.

To obtain area of base, if it is a polygon, divide it into triangles, and find sum of partial areas.

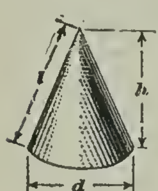
FRUSTUM OF PRISM.



If a section perpendicular to the edges is a triangle, square, parallelogram, or *regular* polygon,

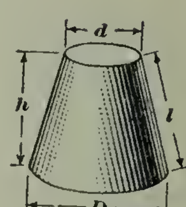
$$V = \frac{\text{sum of lengths of edges}}{\text{number of edges}} \times \text{area of right section.}$$

CONE.



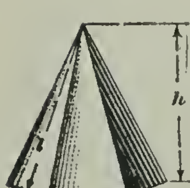
$$C = \tfrac{1}{2} Pl = 1.5708\, d\, l;$$
$$S = 1.5708\, d\, l + .7854\, d^2;$$
$$V = \frac{A\,h}{3} = .2618\, d^2\, h.$$

FRUSTUM OF CONE.



$$C = \tfrac{1}{2} l\,(P + p) = 1.5708\, l\,(D + d);$$
$$S = 1.5708\, l\,(D + d) + .7854\,(D^2 + d^2);$$
$$V = .2618\, h\,(D^2 + D\,d + d^2).$$

PYRAMID.

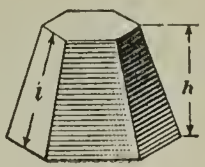


$$C = \tfrac{1}{2} Pl;$$
$$S = \tfrac{1}{2} Pl + A;$$
$$V = \frac{A\,h}{3}.$$

To obtain area of base, divide it into triangles, and find their sum.

FRUSTUM OF PYRAMID.

$$C = \tfrac{1}{2} l (P + p);$$
$$S = \tfrac{1}{2} l (P + p) + A + a;$$
$$V = \tfrac{1}{3} h \left(A + a + \sqrt{A a}\right).$$



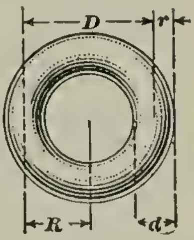
SPHERE.

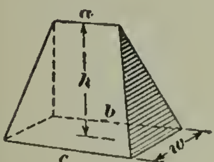
$$S = 3.1416\, d^2 = 12.5664\, r^2;$$
$$V = .5236\, d^3 = 4.1888\, r^3.$$

CIRCULAR RING.

D = mean diameter;
R = mean radius.

$$S = 4 \pi^2 R r = 9.8696\, D d.$$
$$V = 2 \pi^2 R r^2 = 2.4674\, D d^2.$$





WEDGE.

$$V = \tfrac{1}{6} w h (a + b + c).$$

PRISMOID.

A prismoid is a solid having two parallel plane ends, the edges of which are connected by plane triangular or quadrilateral surfaces.

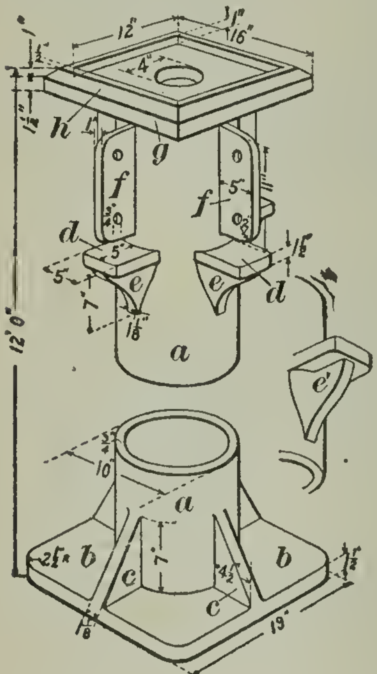
A = area one end;
a = area of other end;
m = area of section midway between ends;
l = perpendicular distance between ends;
$V = \tfrac{1}{6} l (A + a + 4 m).$

The area m is not in general a mean between the areas of the two ends, but its sides are means between the corresponding lengths of the ends.

$$\text{Approximately, } V = \frac{A + a}{2} l.$$

CALCULATING THE WEIGHT OF CASTINGS, ETC.

The first step is to ascertain the number of cubic inches in the casting. To illustrate the method, consider the column shown in the figure to be divided into several parts, as given below. With irregular shapes, as at *e*, follow the principle of "give and take," reducing the shape to an equivalent one, easy to calculate. The operations are then as follows:



	Cu. In.
Cylinder a, excluding cap. Net height = 12 ft. − ($1\frac{1}{2}$ in. + 1 in.) = 141.5 in.; net area = 10″ circle − $8\frac{1}{2}$″ circle = 21.8 sq. in. Contents = 21.8 sq. in. × 141.5 in. =	3,084.7
Base b = 19 in. × 19 in. × $1\frac{1}{2}$ in. = 541.5 cu. in.; deduct area of 10″ circle × $1\frac{1}{2}$″ = 117.8 cu. in.; also, for corners (5″ square — 5″ circle) × $1\frac{1}{2}$″ = 8.1 cu. in. Net contents =	415.6
Triangular ribs c = $\frac{1}{2}$ ($4\frac{1}{2}$ in. × 7 in.) × $1\frac{1}{8}$ in. × 4 =	70.9
Brackets d. Horizontal part *d* is, very nearly, 5 in. × 5 in. × $1\frac{1}{2}$ in. = $37\frac{1}{2}$ cu. in. Vertical part *e*: To compensate for swelled portion next cylinder (see *e′*), consider vertical portion as triangular, with sides 5 in. × 7 in.; its contents are $\frac{1}{2}$ (5 in. × 7 in.) × $1\frac{1}{8}$ in. = 19.7 cu. in. Each bracket = 57.2 cu. in.; 4 brackets = 57.2 × 4 =	228.8
Lugs f = 11 in. × 5 in. × 1 in. = 55 cu. in.; deduct $\frac{1}{2}$ (4″ square — 4″ circle) × 1″ = 1.7 cu. in.; also, two $\frac{3}{4}$″ holes = .9 cu. in. Net contents of each lug, 52.4 cu. in.; 4 lugs = 52.4 × 4 =	209.6
Cap g = (16″ × 16″ — 4″ circle) × $1\frac{1}{2}$″ =	365.2
Carried forward,	4,374.8

Brought forward,	4,374.8
Upper part of cap h = (16″ square − 12″ square) × 1″ thick − deduction for bevel; 256 cu. in. − 144 cu. in. = 112 cu. in. Portion to be deducted consists of 4 wedges, each 16 in. × 1 in. at the back, 13 in. at the edge, which is $1\frac{1}{2}$ in. from back; by rule for wedges, deduction is [$\frac{1}{6}$ × (16 in. + 16 in. + 13 in.) × 1 in. × $1\frac{1}{2}$ in.] × 4 = 45 cu. in. Net contents of part *h* = 112 − 45 =	67.0
Total contents of column =	4,441.8

One cu. ft. of cast iron weighs 450 lb., or 1 cu. in. weighs .26 lb.—called $\frac{1}{4}$ lb., roughly. Hence the weight is 4,442 × .26 = 1,155 lb. This calculation is much more detailed than is usual; generally, no account is taken of rounded corners, small fillets, holes, etc.

When a casting or a rolled shape of steel, etc. is of uniform cross-section throughout—as a rail, **I** beam, or channel—the weight may be very expeditiously determined after calculating the sectional area. A cubic foot of wrought iron weighs 480 lb.; hence, a piece 1 yd. long and 1 in. square contains 36 cu. in., and weighs $\frac{36}{1728}$ of 480 lb. = 10 lb.; or, if 1 ft. long and 1 in. square, weighs $\frac{10}{3} = 3\frac{1}{3}$ lb. Therefore, if the sectional area be known or calculated, the weight per foot may be found by taking $\frac{10}{3}$ the area, or by multiplying the latter by $3\frac{1}{3}$. This result will be in pounds, and, if multiplied by the total length in feet of the member, will give the whole weight.

If the member is made of steel, which weighs 490 lb. per cu. ft., the weight per foot may be determined by multiplying the sectional area by 3.4. For cast iron the multiplier is $3\frac{1}{8}$.

Example.—What is the weight per foot of a 20″ steel **I** beam, having a sectional area of 26.4 sq. in.? 26.4 × 3.4 = 89.76 lb., or, practically, 90 lb. By reference to Table XIX, page 90, it will be seen that this is the weight given.

If the weight per foot is given, and it is desired to find the sectional area, the former, divided by $\frac{10}{3}$, or multiplied by .3, will give the required area. For steel, the multiplier is .294, and for cast iron .32.

CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1-64 TO 100.

Diam.	Circum.	Area.	Diam.	Circum.	Area.
1/64	.0491	.0002	4 3/8	13.7445	15.0330
1/32	.0982	.0008	4 1/2	14.1372	15.9043
1/16	.1963	.0031	4 5/8	14.5299	16.8002
1/8	.3927	.0123	4 3/4	14.9226	17.7206
3/16	.5890	.0276	4 7/8	15.3153	18.6555
1/4	.7854	.0491	5	15.7080	19.6350
5/16	.9817	.0767	5 1/8	16.1007	20.6290
3/8	1.1781	.1104	5 1/4	16.4934	21.6476
7/16	1.3744	.1503	5 3/8	16.8861	22.6907
1/2	1.5708	.1963	5 1/2	17.2788	23.7583
9/16	1.7671	.2485	5 5/8	17.6715	24.8505
5/8	1.9635	.3068	5 3/4	18.0642	25.9673
11/16	2.1598	.3712	5 7/8	18.4569	27.1086
3/4	2.3562	.4418	6	18.8496	28.2744
13/16	2.5525	.5185	6 1/8	19.2423	29.4648
7/8	2.7489	.6013	6 1/4	19.6350	30.6797
15/16	2.9452	.6903	6 3/8	20.0277	31.9191
1	3.1416	.7854	6 1/2	20.4204	33.1831
1 1/8	3.5343	.9940	6 5/8	20.8131	34.4717
1 1/4	3.9270	1.2272	6 3/4	21.2058	35.7848
1 3/8	4.3197	1.4849	6 7/8	21.5985	37.1224
1 1/2	4.7124	1.7671	7	21.9912	38.4846
1 5/8	5.1051	2.0739	7 1/8	22.3839	39.8713
1 3/4	5.4978	2.4053	7 1/4	22.7766	41.2826
1 7/8	5.8905	2.7612	7 3/8	23.1693	42.7184
2	6.2832	3.1416	7 1/2	23.5620	44.1787
2 1/8	6.6759	3.5466	7 5/8	23.9547	45.6636
2 1/4	7.0686	3.9761	7 3/4	24.3474	47.1731
2 3/8	7.4613	4.4301	7 7/8	24.7401	48.7071
2 1/2	7.8540	4.9087	8	25.1328	50.2656
2 5/8	8.2467	5.4119	8 1/8	25.5255	51.8487
2 3/4	8.6394	5.9396	8 1/4	25.9182	53.4563
2 7/8	9.0321	6.4918	8 3/8	26.3109	55.0884
3	9.4248	7.0686	8 1/2	26.7036	56.7451
3 1/8	9.8175	7.6699	8 5/8	27.0963	58.4264
3 1/4	10.2102	8.2958	8 3/4	27.4890	60 1322
3 3/8	10.6029	8.9462	8 7/8	27.8817	61.8625
3 1/2	10.9956	9.6211	9	28.2744	63.6174
3 5/8	11.3883	10.3206	9 1/8	28.6671	65.3968
3 3/4	11.7810	11.0447	9 1/4	29.0598	67.2008
3 7/8	12.1737	11.7933	9 3/8	29.4525	69.0293
4	12.5664	12.5664	9 1/2	29.8452	70.8823
4 1/8	12.9591	13.3641	9 5/8	30.2379	72.7599
4 1/4	13.3518	14.1863	9 3/4	30.6306	74.6621

TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
9⅞	31.0233	76.589	15⅝	49.0875	191.748
10	31.4160	78.540	15¾	49.4802	194.828
10⅛	31.8087	80.516	15⅞	49.8729	197.933
10¼	32.2014	82.516	16	50.2656	201.062
10⅜	32.5941	84.541	16⅛	50.6583	204.216
10½	32.9868	86.590	16¼	51.0510	207.395
10⅝	33.3795	88.664	16⅜	51.4437	210.598
10¾	33.7722	90.763	16½	51.8364	213.825
10⅞	34.1649	92.886	16⅝	52.2291	217.077
11	34.5576	95.033	16¾	52.6218	220.354
11⅛	34.9503	97.205	16⅞	53.0145	223.655
11¼	35.3430	99.402	17	53.4072	226.981
11⅜	35.7357	101.623	17⅛	53.7999	230.331
11½	36.1284	103.869	17¼	54.1926	233.706
11⅝	36.5211	106.139	17⅜	54.5853	237.105
11¾	36.9138	108.434	17½	54.9780	240.529
11⅞	37.3065	110.754	17⅝	55.3707	243.977
12	37.6992	113.098	17¾	55.7634	247.450
12⅛	38.0919	115.466	17⅞	56.1561	250.948
12¼	38.4846	117.859	18	56.5488	254.470
12⅜	38.8773	120.277	18⅛	56.9415	258.016
12½	39.2700	122.719	18¼	57.3342	261.587
12⅝	39.6627	125.185	18⅜	57.7269	265.183
12¾	40.0554	127.677	18½	58.1196	268.803
12⅞	40.4481	130.192	18⅝	58.5123	272.448
13	40.8408	132.733	18¾	58.9050	276.117
13⅛	41.2335	135.297	18⅞	59.2977	279.811
13¼	41.6262	137.887	19	59.6904	283.529
13⅜	42.0189	140.501	19⅛	60.0831	287.272
13½	42.4116	143.139	19¼	60.4758	291.040
13⅝	42.8043	145.802	19⅜	60.8685	294.832
13¾	43.1970	148.490	19½	61.2612	298.648
13⅞	43.5897	151.202	19⅝	61.6539	302.489
14	43.9824	153.938	19¾	62.0466	306.355
14⅛	44.3751	156.700	19⅞	62.4393	310.245
14¼	44.7678	159.485	20	62.8320	314.160
14⅜	45.1605	162.296	20⅛	63.2247	318.099
14½	45.5532	165.130	20¼	63.6174	322.063
14⅝	45.9459	167.990	20⅜	64.0101	326.051
14¾	46.3386	170.874	20½	64.4028	330.064
14⅞	46.7313	173.782	20⅝	64.7955	334.102
15	47.1240	176.715	20¾	65.1882	338.164
15⅛	47.5167	179.673	20⅞	65.5809	342.250
15¼	47.9094	182.655	21	65.9736	346.361
15⅜	48.3021	185.661	21⅛	66.3663	350.497
15½	48.6948	188.692	21¼	66.7590	354.657

TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
$21\frac{3}{8}$	67.1517	358.842	$27\frac{1}{8}$	85.2159	577.870
$21\frac{1}{2}$	67.5444	363.051	$27\frac{1}{4}$	85.6086	583.209
$21\frac{5}{8}$	67.9371	367.285	$27\frac{3}{8}$	86.0013	588.571
$21\frac{3}{4}$	68.3298	371.543	$27\frac{1}{2}$	86.3940	593.959
$21\frac{7}{8}$	68.7225	375.826	$27\frac{5}{8}$	86.7867	599.371
22	69.1152	380.134	$27\frac{3}{4}$	87.1794	604.807
$22\frac{1}{8}$	69.5079	384.466	$27\frac{7}{8}$	87.5721	610.268
$22\frac{1}{4}$	69.9006	388.822	28	87.9648	615.754
$22\frac{3}{8}$	70.2933	393.203	$28\frac{1}{8}$	88.3575	621.264
$22\frac{1}{2}$	70.6860	397.609	$28\frac{1}{4}$	88.7502	626.798
$22\frac{5}{8}$	71.0787	402.038	$28\frac{3}{8}$	89.1429	632.357
$22\frac{3}{4}$	71.4714	406.494	$28\frac{1}{2}$	89.5356	637.941
$22\frac{7}{8}$	71.8641	410.973	$28\frac{5}{8}$	89.9283	643.549
23	72.2568	415.477	$28\frac{3}{4}$	90.3210	649.182
$23\frac{1}{8}$	72.6495	420.004	$28\frac{7}{8}$	90.7137	654.840
$23\frac{1}{4}$	73.0422	424.558	29	91.1064	660.521
$23\frac{3}{8}$	73.4349	429.135	$29\frac{1}{8}$	91.4991	666.228
$23\frac{1}{2}$	73.8276	433.737	$29\frac{1}{4}$	91.8918	671.959
$23\frac{5}{8}$	74.2203	438.364	$29\frac{3}{8}$	92.2845	677.714
$23\frac{3}{4}$	74.6130	443.015	$29\frac{1}{2}$	92.6772	683.494
$23\frac{7}{8}$	75.0057	447.690	$29\frac{5}{8}$	93.0699	689.299
24	75.3984	452.390	$29\frac{3}{4}$	93.4626	695.128
$24\frac{1}{8}$	75.7911	457.115	$29\frac{7}{8}$	93.8553	700.982
$24\frac{1}{4}$	76.1838	461.864	30	94.2480	706.860
$24\frac{3}{8}$	76.5765	466.638	$30\frac{1}{8}$	94.6407	712.763
$24\frac{1}{2}$	76.9692	471.436	$30\frac{1}{4}$	95.0334	718.690
$24\frac{5}{8}$	77.3619	476.259	$30\frac{3}{8}$	95.4261	724.642
$24\frac{3}{4}$	77.7546	481.107	$30\frac{1}{2}$	95.8188	730.618
$24\frac{7}{8}$	78.1473	485.979	$30\frac{5}{8}$	96.2115	736.619
25	78.5400	490.875	$30\frac{3}{4}$	96.6042	742.645
$25\frac{1}{8}$	78.9327	495.796	$30\frac{7}{8}$	96.9969	748.695
$25\frac{1}{4}$	79.3254	500.742	31	97.3896	754.769
$25\frac{3}{8}$	79.7181	505.712	$31\frac{1}{8}$	97.7823	760.869
$25\frac{1}{2}$	80.1108	510.706	$31\frac{1}{4}$	98.1750	766.992
$25\frac{5}{8}$	80.5035	515.726	$31\frac{3}{8}$	98.5677	773.140
$25\frac{3}{4}$	80.8962	520.769	$31\frac{1}{2}$	98.9604	779.313
$25\frac{7}{8}$	81.2889	525.838	$31\frac{5}{8}$	99.3531	785.510
26	81.6816	530.930	$31\frac{3}{4}$	99.7458	791.732
$26\frac{1}{8}$	82.0743	536.048	$31\frac{7}{8}$	100.1385	797.979
$26\frac{1}{4}$	82.4670	541.190	32	100.5312	804.250
$26\frac{3}{8}$	82.8597	546.356	$32\frac{1}{8}$	100.9239	810.545
$26\frac{1}{2}$	83.2524	551.547	$32\frac{1}{4}$	101.3166	816.865
$26\frac{5}{8}$	83.6451	556.763	$32\frac{3}{8}$	101.7093	823.210
$26\frac{3}{4}$	84.0378	562.003	$32\frac{1}{2}$	102.1020	829.579
$26\frac{7}{8}$	84.4305	567.267	$32\frac{5}{8}$	102.4947	835.972
27	84.8232	572.557	$32\frac{3}{4}$	102.8874	842.391

TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
32⅞	103.280	848.833	38⅝	121.344	1,171.731
33	103.673	855.301	38¾	121.737	1,179.327
33⅛	104.065	861.792	38⅞	122.130	1,186.948
33¼	104.458	868.309	39	122.522	1,194.593
33⅜	104.851	874.850	39⅛	122.915	1,202.263
33½	105.244	881.415	39¼	123.308	1,209.958
33⅝	105.636	888.005	39⅜	123.700	1,217.677
33¾	106.029	894.620	39½	124.093	1,225.420
33⅞	106.422	901.259	39⅝	124.486	1,233.188
34	106.814	907.922	39¾	124.879	1,240.981
34⅛	107.207	914.611	39⅞	125.271	1,248.798
34¼	107.600	921.323	40	125.664	1,256.640
34⅜	107.992	928.061	40⅛	126.057	1,264.510
34½	108.385	934.822	40¼	126.449	1,272.400
34⅝	108.778	941.609	40⅜	126.842	1,280.310
34¾	109.171	948.420	40½	127.235	1,288.250
34⅞	109.563	955.255	40⅝	127.627	1,296.220
35	109.956	962.115	40¾	128.020	1,304.210
35⅛	110.349	969.000	40⅞	128.413	1,312.220
35¼	110.741	975.909	41	128.806	1,320.260
35⅜	111.134	982.842	41⅛	129.198	1,328.320
35½	111.527	989.800	41¼	129.591	1,336.410
35⅝	111.919	996.783	41⅜	129.984	1,344.520
35¾	112.312	1,003.790	41½	130.376	1,352.660
35⅞	112.705	1,010.822	41⅝	130.769	1,360.820
36	113.098	1,017.878	41¾	131.162	1,369.000
36⅛	113.490	1,024.960	41⅞	131.554	1,377.210
36¼	113.883	1,032.065	42	131.947	1,385.450
36⅜	114.276	1,039.195	42⅛	132.340	1,393.700
36½	114.668	1,046.349	42¼	132.733	1,401.990
36⅝	115.061	1,053.528	42⅜	133.125	1,410.300
36¾	115.454	1,060.732	42½	133.518	1,418.630
36⅞	115.846	1,067.960	42⅝	133.911	1,426.990
37	116.239	1,075.213	42¾	134.303	1,435.370
37⅛	116.632	1,082.490	42⅞	134.696	1,443.770
37¼	117.025	1,089.792	43	135.089	1,452.200
37⅜	117.417	1,097.118	43⅛	135.481	1,460.660
37½	117.810	1,104.469	43¼	135.874	1,469.140
37⅝	118.203	1,111.844	43⅜	136.267	1,477.640
37¾	118.595	1,119.244	43½	136.660	1,486.170
37⅞	118.988	1,126.669	43⅝	137.052	1,494.730
38	119.381	1,134.118	43¾	137.445	1,503.300
38⅛	119.773	1,141.591	43⅞	137.838	1,511.910
38¼	120.166	1,149.089	44	138.230	1,520.530
38⅜	120.559	1,156.612	44⅛	138.623	1,529.190
38½	120.952	1,164.159	44¼	139.016	1,537.860

TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
44⅜	139.408	1,546.56	50⅛	157.473	1,973.33
44½	139.801	1,555.29	50¼	157.865	1,983.18
44⅝	140.194	1,564.04	50⅜	158.258	1,993.06
44¾	140.587	1,572.81	50½	158.651	2,002.97
44⅞	140.979	1,581.61	50⅝	159.043	2,012.89
45	141.372	1,590.43	50¾	159.436	2,022.85
45⅛	141.765	1,599.28	50⅞	159.829	2,032.82
45¼	142.157	1,608.16	51	160.222	2,042.83
45⅜	142.550	1,617.05	51⅛	160.614	2,052.85
45½	142.943	1,625.97	51¼	161.007	2,062.90
45⅝	143.335	1,634.92	51⅜	161.400	2,072.98
45¾	143.728	1,643.89	51½	161.792	2,083.08
45⅞	144.121	1,652.89	51⅝	162.185	2,093.20
46	144.514	1,661.91	51¾	162.578	2,103.35
46⅛	144.906	1,670.95	51⅞	162.970	2,113.52
46¼	145.299	1,680.02	52	163.363	2,123.72
46⅜	145.692	1,689.11	52⅛	163.756	2,133.94
46½	146.084	1,698.23	52¼	164.149	2,144.19
46⅝	146.477	1,707.37	52⅜	164.541	2,154.46
46¾	146.870	1,716.54	52½	164.934	2,164.76
46⅞	147.262	1,725.73	52⅝	165.327	2,175.08
47	147.655	1,734.95	52¾	165.719	2,185.42
47⅛	148.048	1,744.19	52⅞	166.112	2,195.79
47¼	148.441	1,753.45	53	166.505	2,206.19
47⅜	148.833	1,762.74	53⅛	166.897	2,216.61
47½	149.226	1,772.06	53¼	167.290	2,227.05
47⅝	149.619	1,781.40	53⅜	167.683	2,237.52
47¾	150.011	1,790.76	53½	168.076	2,248.01
47⅞	150.404	1,800.15	53⅝	168.468	2,258.53
48	150.797	1,809.56	53¾	168.861	2,269.07
48⅛	151.189	1,819.00	53⅞	169.254	2,279.64
48¼	151.582	1,828.46	54	169.646	2,290.23
48⅜	151.975	1,837.95	54⅛	170.039	2,300.84
48½	152.368	1,847.46	54¼	170.432	2,311.48
48⅝	152.760	1,856.99	54⅜	170.824	2,322.15
48¾	153.153	1,866.55	54½	171.217	2,332.83
48⅞	153.546	1,876.14	54⅝	171.610	2,343.55
49	153.938	1,885.75	54¾	172.003	2,354.29
49⅛	154.331	1,895.38	54⅞	172.395	2,365.05
49¼	154.724	1,905.04	55	172.788	2,375.83
49⅜	155.116	1,914.72	55⅛	173.181	2,386.65
49½	155.509	1,924.43	55¼	173.573	2,397.48
49⅝	155.902	1,934.16	55⅜	173.966	2,408.34
49¾	156.295	1,943.91	55½	174.359	2,419.23
49⅞	156.687	1,953.69	55⅝	174.751	2,430.14
50	157.080	1,963.50	55¾	175.144	2,441.07

TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
55⅞	175.537	2,452.03	61⅝	193.601	2,982.67
56	175.930	2,463.01	61¾	193.994	2,994.78
56⅛	176.322	2,474.02	61⅞	194.386	3,006.92
56¼	176.715	2,485.05	62	194.779	3,019.08
56⅜	177.108	2,496.11	62⅛	195.172	3,031.26
56½	177.500	2,507.19	62¼	195.565	3,043.47
56⅝	177.893	2,518.30	62⅜	195.957	3,055.71
56¾	178.286	2,529.43	62½	196.350	3,067.97
56⅞	178.678	2,540.58	62⅝	196.743	3,080.25
57	179.071	2,551.76	62¾	197.135	3,092.56
57⅛	179.464	2,562.97	62⅞	197.528	3,104.89
57¼	179.857	2,574.20	63	197.921	3,117.25
57⅜	180.249	2,585.45	63⅛	198.313	3,129.64
57½	180.642	2,596.73	63¼	198.706	3,142.04
57⅝	181.035	2,608.03	63⅜	199.099	3,154.47
57¾	181.427	2,619.36	63½	199.492	3,166.93
57⅞	181.820	2,630.71	63⅝	199.884	3,179.41
58	182.213	2,642.09	63¾	200.277	3,191.91
58⅛	182.605	2,653.49	63⅞	200.670	3,204.44
58¼	182.998	2,664.91	64	201.062	3,217.00
58⅜	183.391	2,676.36	64⅛	201.455	3,229.58
58½	183.784	2,687.84	64¼	201.848	3,242.18
58⅝	184.176	2,699.33	64⅜	202.240	3,254.81
58¾	184.569	2,710.86	64½	202.633	3,267.46
58⅞	184.962	2,722.41	64⅝	203.026	3,280.14
59	185.354	2,733.98	64¾	203.419	3,292.84
59⅛	185.747	2,745.57	64⅞	203.811	3,305.56
59¼	186.140	2,757.20	65	204.204	3,318.31
59⅜	186.532	2,768.84	65⅛	204.597	3,331.09
59½	186.925	2,780.51	65¼	204.989	3,343.89
59⅝	187.318	2,792.21	65⅜	205.382	3,356.71
59¾	187.711	2,803.93	65½	205.775	3,369.56
59⅞	188.103	2,815.67	65⅝	206.167	3,382.44
60	188.496	2,827.44	65¾	206.560	3,395.33
60⅛	188.889	2,839.23	65⅞	206.953	3,408.26
60¼	189.281	2,851.05	66	207.346	3,421.20
60⅜	189.674	2,862.89	66⅛	207.738	3,434.17
60½	190.067	2,874.76	66¼	208.131	3,447.17
60⅝	190.459	2,886.65	66⅜	208.524	3,460.19
60¾	190.852	2,898.57	66½	208.916	3,473.24
60⅞	191.245	2,910.51	66⅝	209.309	3,486.30
61	191.638	2,922.47	66¾	209.702	3,499.40
61⅛	192.030	2,934.46	66⅞	210.094	3,512.52
61¼	192.423	2,946.48	67	210.487	3,525.66
61⅜	192.816	2,958.52	67⅛	210.880	3,538.83
61½	193.208	2,970.58	67¼	211.273	3,552.02

TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
67⅜	211.665	3,565.24	73⅛	229.729	4,199.74
67½	212.058	3,578.48	73¼	230.122	4,214.11
67⅝	212.451	3,591.74	73⅜	230.515	4,228.51
67¾	212.843	3,605.04	73½	230.908	4,242.93
67⅞	213.236	3,618.35	73⅝	231.300	4,257.37
68	213.629	3,631.69	73¾	231.693	4,271.84
68⅛	214.021	3,645.05	73⅞	232.086	4,286.33
68¼	214.414	3,658.44	74	232.478	4,300.85
68⅜	214.807	3,671.86	74⅛	232.871	4,315.39
68½	215.200	3,685.29	74¼	233.264	4,329.96
68⅝	215.592	3,698.76	74⅜	233.656	4,344.55
68¾	215.985	3,712.24	74½	234.049	4,359.17
68⅞	216.378	3,725.75	74⅝	234.442	4,373.81
69	216.770	3,739.29	74¾	234.835	4,388.47
69⅛	217.163	3,752.85	74⅞	235.227	4,403.16
69¼	217.556	3,766.43	75	235.620	4,417.87
69⅜	217.948	3,780.04	75⅛	236.013	4,432.61
69½	218.341	3;793.68	75¼	236.405	4,447.38
69⅝	218.734	3,807.34	75⅜	236.798	4,462.16
69¾	219.127	3,821.02	75½	237.191	4,476.98
69⅞	219.519	3,834.73	75⅝	237.583	4,491.81
70	219.912	3,848.46	75¾	237.976	4,506.67
70⅛	220.305	3,862.22	75⅞	238.369	4,521.56
70¼	220.697	3,876.00	76	238.762	4,536.47
70⅜	221.090	3,889.80	76⅛	239.154	4,551.41
70½	221.483	3,903.63	76¼	239.547	4,566.36
70⅝	221.875	3,917.49	76⅜	239.940	4,581.35
70¾	222.268	3,931.37	76½	240.332	4,596.36
70⅞	222.661	3,945.27	76⅝	240.725	4,611.39
71	223.054	3,959.20	76¾	241.118	4,626.45
71⅛	223.446	3,973.15	76⅞	241.510	4,641.53
71¼	223.839	3,987.13	77	241.903	4,656.64
71⅜	224.232	4,001.13	77⅛	242.296	4,671.77
71½	224.624	4,015.16	77¼	242.689	4,686.92
71⅝	225.017	4,029.21	77⅜	243.081	4,702.10
71¾	225.410	4,043.29	77½	243.474	4,717.31
71⅞	225.802	4,057.39	77⅝	243.867	4,732.54
72	226.195	4,071.51	77¾	244.259	4,747.79
72⅛	226.588	4,085.66	77⅞	244.652	4,763.07
72¼	226.981	4,099.84	78	245.045	4,778.37
72⅜	227.373	4,114.04	78⅛	245.437	4,793.70
72½	227.766	4,128.26	78¼	245.830	4,809.05
72⅝	228.159	4,142.51	78⅜	246.223	4,824.43
72¾	228.551	4,156.78	78½	246.616	4,839.83
72⅞	228.944	4,171.08	78⅝	247.008	4,855.26
73	229.337	4,185.40	78¾	247.401	4,870.71

TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
78⅞	247.794	4,886.18	84⅝	265.858	5,624.56
79	248.186	4,901.68	84¾	266.251	5,641.18
79⅛	248.579	4,917.21	84⅞	266.643	5,657.84
79¼	248.972	4,932.75	85	267.036	5,674.51
79⅜	249.364	4,948.33	85⅛	267.429	5,691.22
79½	249.757	4,963.92	85¼	267.821	5,707.94
79⅝	250.150	4,979.55	85⅜	268.214	5,724.69
79¾	250.543	4,995.19	85½	268.607	5,741.47
79⅞	250.935	5,010.86	85⅝	268.999	5,758.27
80	251.328	5,026.56	85¾	269.392	5,775.10
80⅛	251.721	5,042.28	85⅞	269.785	5,791.94
80¼	252.113	5,058.03	86	270.178	5,808.82
80⅜	252.506	5,073.79	86⅛	270.570	5,825.72
80½	252.899	5,089.59	86¼	270.963	5,842.64
80⅝	253.291	5,105.41	86⅜	271.356	5,859.59
80¾	253.684	5,121.25	86½	271.748	5,876.56
80⅞	254.077	5,137.12	86⅝	272.141	5,893.55
81	254.470	5,153.01	86¾	272.534	5,910.58
81⅛	254.862	5,168.93	86⅞	272.926	5,927.62
81¼	255.255	5,184.87	87	273.319	5,944.69
81⅜	255.648	5,200.83	87⅛	273.712	5,961.79
81½	256.040	5,216.82	87¼	274.105	5,978.91
81⅝	256.433	5,232.84	87⅜	274.497	5,996.05
81¾	256.826	5,248.88	87½	274.890	6,013.22
81⅞	257.218	5,264.94	87⅝	275.283	6,030.41
82	257.611	5,281.03	87¾	275.675	6,047.63
82⅛	258.004	5,297.14	87⅞	276.068	6,064.87
82¼	258.397	5,313.28	88	276.461	6,082.14
82⅜	258.789	5,329.44	88⅛	276.853	6,099.43
82½	259.182	5,345.63	88¼	277.246	6,116.74
82⅝	259.575	5,361.84	88⅜	277.629	6,134.08
82¾	259.967	5,378.08	88½	278.032	6,151.45
82⅞	260.360	5,394.34	88⅝	278.424	6,168.84
83	250.753	5,410.62	88¾	278.817	6,186.25
83⅛	261.145	5,426.93	88⅞	279.210	6,203.69
83¼	261.538	5,443.26	89	279.602	6,221.15
83⅜	261.931	5,459.62	89⅛	279.995	6,238.64
83½	262.324	5,476.01	89¼	280.388	6,256.15
83⅝	262.716	5,492.41	89⅜	280.780	6,273.69
83¾	263.109	5,508.84	89½	281.173	6,291.25
83⅞	263.502	5,525.30	89⅝	281.566	6,308.84
84	263.894	5,541.78	89¾	281.959	6,326.45
84⅛	264.287	5,558.29	89⅞	282.351	6,344.08
84¼	264.680	5,574.82	90	282.744	6,361.74
84⅜	265.072	5,591.37	90⅛	283.137	6,379.42
84½	265.465	5,607.95	90¼	283.529	6,397.13

TABLE—(*Continued*).

Diam.	Circum.	Area.	Diam.	Circum.	Area.
90⅜	283.922	6,414.86	95¼	299.237	7,125.59
90½	284.315	6,432.62	95⅜	299.630	7,144.31
90⅝	284.707	6,450.40	95½	300.023	7,163.04
90¾	285.100	6,468.21	95⅝	300.415	7,181.81
90⅞	285.493	6,486.04	95¾	300.808	7,200.60
91	285.886	6,503.90	95⅞	301.201	7,219.41
91⅛	286.278	6,521.78	96	301.594	7,238.25
91¼	286.671	6,539.68	96⅛	301.986	7,257.11
91⅜	287.064	6,557.61	96¼	302.379	7,275.99
91½	287.456	6,575.56	96⅜	302.772	7,294.91
91⅝	287.849	6,593.54	96½	303.164	7,313.84
91¾	288.242	6,611.55	96⅝	303.557	7,332.80
91⅞	288.634	6,629.57	96¾	303.950	7,351.79
92	289.027	6,647.63	96⅞	304.342	7,370.79
92⅛	289.420	6,665.70	97	304.735	7,389.83
92¼	289.813	6,683.80	97⅛	305.128	7,408.89
92⅜	290.205	6,701.93	97¼	305.521	7,427.97
92½	290.598	6,720.08	97⅜	305.913	7,447.08
92⅝	290.991	6,738.25	97½	306.306	7,466.21
92¾	291.383	6,756.45	97⅝	306.699	7,485.37
92⅞	291.776	6,774.68	97¾	307.091	7,504.55
93	292.169	6,792.92	97⅞	307.484	7,523.75
93⅛	292.562	6,811.20	98	307.877	7,542.98
93¼	292.954	6,829.49	98⅛	308.270	7,562.24
93⅜	293.347	6,847.82	98¼	308.662	7,581.52
93½	293.740	6,866.16	98⅜	309.055	7,600.82
93⅝	294.132	6,884.53	98½	309.448	7,620.15
93¾	294.525	6,902.93	98⅝	309.840	7,639.50
93⅞	294.918	6,921.35	98¾	310.233	7,658.88
94	295.310	6,939.79	98⅞	310.626	7,678.28
94⅛	295.703	6,958.26	99	311.018	7,697.71
94¼	296.096	6,976.76	99⅛	311.411	7,717.16
94⅜	296.488	6,995.28	99¼	311.804	7,736.63
94½	296.881	7,013.82	99⅜	312.196	7,756.13
94⅝	297.274	7,032.39	99½	312.589	7,775.66
94¾	297.667	7,050.98	99⅝	312.982	7,795.21
94⅞	298.059	7,069.59	99¾	313.375	7,814.78
95	298.452	7,088.24	99⅞	313.767	7,834.38
95⅛	298.845	7,106.90	100	314.160	7,854.00

The preceding table may be used to determine the diameter when the circumference or area is known. Thus, the diameter of a circle having an area of 7,200 sq. in. is, approximately, 95¾ in.

DECIMAL EQUIVALENTS OF PARTS OF ONE INCH.

1-64	.015625	17-64	.265625	33-64	.515625	49-64	.765625
1-32	.031250	9-32	.281250	17-32	.531250	25-32	.781250
3-64	.046875	19-64	.296875	35-64	.546875	51-64	.796875
1-16	.062500	**5-16**	.312500	**9-16**	.562500	**13-16**	.812500
5-64	.078125	21-64	.328125	37-64	.578125	53-64	.828125
3-32	.093750	11-32	.343750	19-32	.593750	27-32	.843750
7-64	.109375	23-64	.359375	39-64	.609375	55-64	.859375
1-8	.125000	**3-8**	.375000	**5-8**	.625000	**7-8**	.875000
9-64	.140625	25-64	.390625	41-64	.640625	57-64	.890625
5-32	.156250	13-32	.406250	21-32	.656250	29-32	.906250
11-64	.171875	27-64	.421875	43-64	.671875	59-64	.921875
3-16	.187500	**7-16**	.437500	**11-16**	.687500	**15-16**	.937500
13-64	.203125	29-64	.453125	45-64	.703125	61-64	.953125
7-32	.218750	15-32	.468750	23-32	.718750	31-32	.968750
15-64	.234375	31-64	.484375	47-64	.734375	63-64	.984375
1-4	.250000	**1-2**	.500000	**3-4**	.750000	**1**	**1**

DECIMALS OF A FOOT FOR EACH 1-32 OF AN INCH.

Inch.	0″	1″	2″	3″	4″	5″
0	0	.0833	.1667	.2500	.3333	.4167
$\frac{1}{32}$	.0026	.0859	.1693	.2526	.3359	.4193
$\frac{1}{16}$	.0052	.0885	.1719	.2552	.3385	.4219
$\frac{3}{32}$	.0078	.0911	.1745	.2578	.3411	.4245
$\frac{1}{8}$	.0104	.0937	.1771	.2604	.3437	.4271
$\frac{5}{32}$	.0130	.0964	.1797	.2630	.3464	.4297
$\frac{3}{16}$	.0156	.0990	.1823	.2656	.3490	.4323
$\frac{7}{32}$	.0182	.1016	.1849	.2682	.3516	.4349
$\frac{1}{4}$	.0208	.1042	.1875	.2708	.3542	.4375
$\frac{9}{32}$	.0234	.1068	.1901	.2734	.3568	.4401
$\frac{5}{16}$	.0260	.1094	.1927	.2760	.3594	.4427
$\frac{11}{32}$	.0286	.1120	.1953	.2786	.3620	.4453
$\frac{3}{8}$	.0312	.1146	.1979	.2812	.3646	.4479
$\frac{13}{32}$	.0339	.1172	.2005	.2839	.3672	.4505
$\frac{7}{16}$	.0365	.1198	.2031	.2865	.3698	.4531
$\frac{15}{32}$	.0391	.1224	.2057	.2891	.3724	.4557
$\frac{1}{2}$	.0417	.1250	.2083	.2917	.3750	.4583
$\frac{17}{32}$	.0443	.1276	.2109	.2943	.3776	.4609
$\frac{9}{16}$	.0469	.1302	.2135	.2969	.3802	.4635
$\frac{19}{32}$	.0495	.1328	.2161	.2995	.3828	.4661
$\frac{5}{8}$	.0521	.1354	.2188	.3021	.3854	.4688
$\frac{21}{32}$	.0547	.1380	.2214	.3047	.3880	.4714
$\frac{11}{16}$	.0573	.1406	.2240	.3073	.3906	.4740
$\frac{23}{32}$	.0599	.1432	.2266	.3099	.3932	.4766

TABLE—(*Continued*).

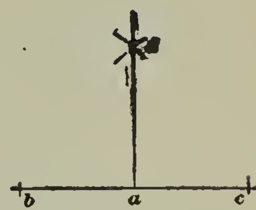
Inch.	0″	1″	2″	3″	4″	5″
$\frac{3}{4}$	.0625	.1458	.2292	.3125	.3958	.4792
$\frac{25}{32}$	.0651	.1484	.2318	.3151	.3984	.4818
$\frac{13}{16}$	.0677	.1510	.2344	.3177	.4010	.4844
$\frac{27}{32}$	.0703	.1536	.2370	.3203	.4036	.4870
$\frac{7}{8}$	.0729	.1562	.2396	.3229	.4062	.4896
$\frac{29}{32}$	.0755	.1589	.2422	.3255	.4089	.4922
$\frac{15}{16}$	.0781	.1615	.2448	.3281	.4115	.4948
$\frac{31}{32}$	.0807	.1641	.2474	.3307	.4141	.4974

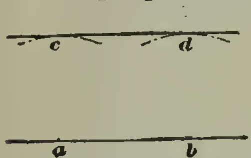
DECIMALS OF A FOOT FOR EACH 1-32 OF AN INCH.

Inch.	6″	7″	8″	9″	10″	11″
0	.5000	.5833	.6667	.7500	.8333	.9167
$\frac{1}{32}$	.5026	.5859	.6693	.7526	.8359	.9193
$\frac{1}{16}$	.5052	.5885	.6719	.7552	.8385	.9219
$\frac{3}{32}$	.5078	.5911	.6745	.7578	.8411	.9245
$\frac{1}{8}$	.5104	.5937	.6771	.7604	.8437	.9271
$\frac{5}{32}$	.5130	.5964	.6797	.7630	.8464	.9297
$\frac{3}{16}$	.5156	.5990	.6823	.7656	.8490	.9323
$\frac{7}{32}$	.5182	.6016	.6849	.7682	.8516	.9349
$\frac{1}{4}$	.5208	.6042	.6875	.7708	.8542	.9375
$\frac{9}{32}$	.5234	.6068	.6901	.7734	.8568	.9401
$\frac{5}{16}$	.5260	.6094	.6927	.7760	.8594	.9427
$\frac{11}{32}$	.5286	.6120	.6953	.7786	.8620	.9453
$\frac{3}{8}$	.5312	.6146	.6979	.7812	.8646	.9479
$\frac{13}{32}$	.5339	.6172	.7005	.7839	.8672	.9505
$\frac{7}{16}$	.5365	.6198	.7031	.7865	.8698	.9531
$\frac{15}{32}$	.5391	.6224	.7057	.7891	.8724	.9557
$\frac{1}{2}$	.5417	.6250	.7083	.7917	.8750	.9583
$\frac{17}{32}$	.5443	.6276	.7109	.7943	.8776	.9609
$\frac{9}{16}$	.5469	.6302	.7135	.7969	.8802	.9635
$\frac{19}{32}$	.5495	.6328	.7161	.7995	.8828	.9661
$\frac{5}{8}$	.5521	.6354	.7188	.8021	.8854	.9688
$\frac{21}{32}$	.5547	.6380	.7214	.8047	.8880	.9714
$\frac{11}{16}$	.5573	.6406	.7240	.8073	.8906	.9740
$\frac{23}{32}$	.5599	.6432	.7266	.8099	.8932	.9766
$\frac{3}{4}$	.5625	.6458	.7292	.8125	.8958	.9792
$\frac{25}{32}$	.5651	.6484	.7318	.8151	.8984	.9818
$\frac{13}{16}$	.5677	.6510	.7344	.8177	.9010	.9844
$\frac{27}{32}$	.5703	.6536	.7370	.8203	.9036	.9870
$\frac{7}{8}$	.5729	.6562	.7396	.8229	.9062	.9896
$\frac{29}{32}$	.5755	.6589	.7422	.8255	.9089	.9922
$\frac{15}{16}$	.5781	.6615	.7448	.8281	.9115	.9948
$\frac{31}{32}$	.5807	.6641	.7474	.8307	.9141	.9974

GEOMETRICAL DRAWING.

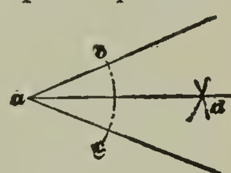
To erect a perpendicular to the line b c at the point a. With *a* as a center, and any radius, as *a b*, strike arcs cutting the line at *b* and *c*. From *b* and *c* as centers, and any radius greater than *b a*, strike arcs intersecting at *d*. Draw *d a*, which will be perpendicular to *b c* at *a*.

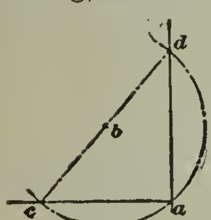




To draw a line parallel to a b. At any points *a* and *b*, with a radius equal to the required distance between the lines, draw arcs at *c* and *d*. The line *c d*, tangent to the arcs, will be the required parallel.

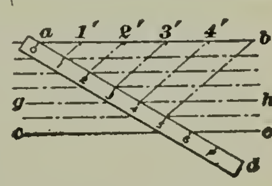
To bisect the angle b a c. With *a* as a center, strike an arc cutting the sides of the angle in *b* and *c*. With *b* and *c* as centers, and any radius, strike arcs intersecting, as at *d*. Draw *d a*, the bisector.



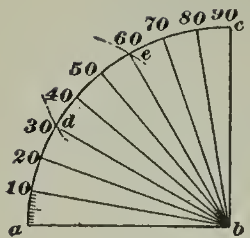


To erect a perpendicular at the end of a line. Take a center anywhere above the line, as at *b*. Strike an arc passing through *a* and cutting the given line at *c*. Draw a line through *c* and *b*, cutting the arc at *d*. Draw the line *a d*, which will be the required perpendicular.

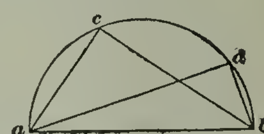
To divide a line into any number of equal parts. Let it be required to divide the line *a b* into 5 equal parts. Draw any line *a d*, and point off 5 equal divisions, as shown. From *5* draw a line to *b* and draw *4–4′*, *3–3′*, etc. parallel to *5 b*.



To divide a space between two parallel lines or surfaces (for example, the spacing of risers in a stairway). Draw *a b* and *c e* the given distance apart. Then move a scale along them, until as many spaces are included along *a d* as there are number of divisions required. Mark the points *1, 2, 3,* etc., and draw lines through them parallel to *a b* and *c e*.

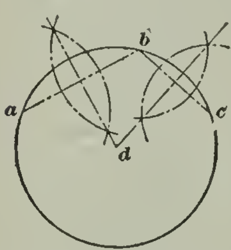


The magnitude of an angle depends not upon the length of its sides, but upon the number of degrees contained in the arc of a circle drawn with the vertex as a center. The circle is divided into 360 equal parts, called *degrees*. To divide a quadrant as shown in the figure, first divide it into 3 parts by the arcs at *e* and *d*, chords *e d* and *a e* being equal to the radius. Then subdivide with dividers.



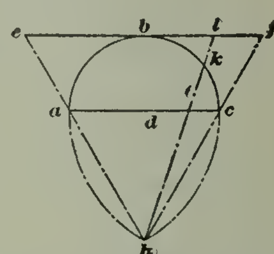
An *inscribed* angle has its vertex (as *c* or *d*) in the circumference of a circle. Any angle inscribed in a semicircle is a right angle, as *a e b*, or *a d b*.

To draw a circle through three points not in a straight line, as

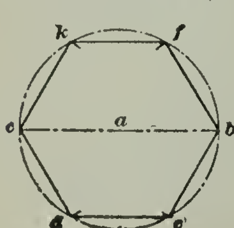


a, *b*, and *c*. Bisect *a b* and also *b c*. The two bisectors will intersect in a point *d*, which will be the center of the required circle.

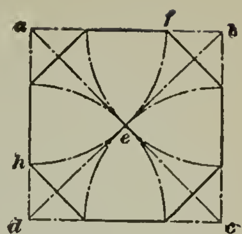
To find the center of a circular arc, as *a b e*, take a point, as *b* on the curve, and draw *b a* and *b c*. Bisect these lines by perpendiculars; the intersection *d* will be the required center.



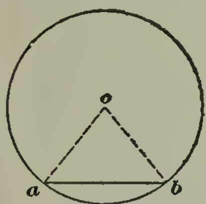
To find a straight line nearly equal to a semi-circumference, as *a b e*. On the diameter construct the equilateral triangle *a c h*. Through *a* and *c* draw *h e* and *h f*. Then *e f* is the length of the semi-circumference. Draw any line, as *h k l*; then *l f* is almost exactly the length of arc *k e*, and *b l* that of arc *b k*.



To construct a hexagon from a given side. Describe a circle with a radius *a b* equal to the given side. Draw a diameter as *c b*. From *c* and *b* as centers, and a radius equal to the given side, draw arcs cutting the circle at *k*, *d*, *f*, and *e*. Connect *c*, *k*, *f*, *b*, *e*, and *d*.

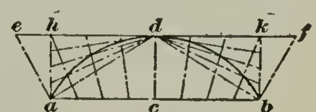


To inscribe an octagon in a square. Draw the diagonals ac and bd. With a as a center, and ae as a radius, strike an arc cutting the sides of the square at f and h. Repeat the operation at b, c, and d, and draw lines connecting the eight points thus found to form the figure required.

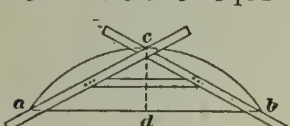


To draw any regular polygon in a circle. Divide 360° by the number of sides; the quotient will be the angle aob. Lay off this angle at the center with a protractor, and draw its chord, a side of the required polygon. Step this side around on the circumference, and connect the points found.

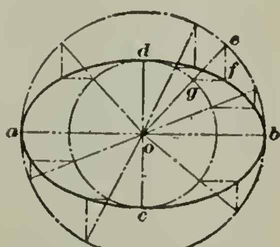
To draw a segment of a circle, having given the chord ab and height cd. Draw cf, through d, parallel to ab; also, ad and db. Draw ac and bf perpendicular to ad and db; also ah and bk perpendicular to ab. Divide cd, df, ac, cb, ah, and bk into the same number of equal parts. Draw lines connecting the points as shown, and trace the curve through the intersections.



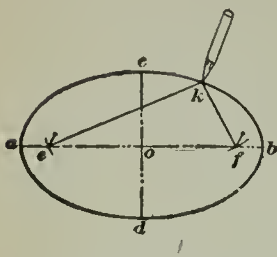
To draw a segment of a circle by means of a fixed triangle. Let ab be the required chord, and dc the rise. Drive nails at a and b. Make a triangle, as shown, from thin strips, so that the vertex comes at c, and stiffen it with the cross-brace. Now, by moving the triangle, always keeping the sides touching the nails at a and b, the arc may be traced by a pencil held at c.



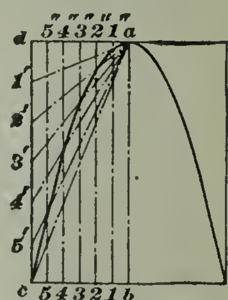
To draw an ellipse, having given the axes. Draw concentric circles whose diameters are equal to the axes ab and cd. From o draw any radius, as oe. From g, where oe cuts the inner circle, draw gf parallel to the major axis ab. From e, draw ef parallel to the minor axis dc. The intersection f gives a point on the ellipse. Other points are similarly found.



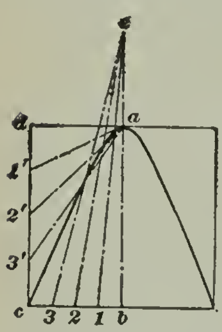
To draw an ellipse with a string, having given the axes a b and c d. With *c* as a center, and a radius equal to *o b*, strike arcs cutting the major axis at *e* and *f*, the foci of the ellipse. Stick pins at *e* and *f*, and attach a string as shown, the length of the string being equal to the length of the major axis. Keep the string stretched with a pencil point, and sweep around the ellipse.



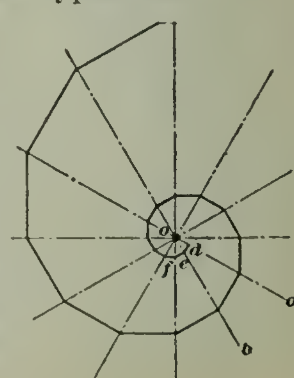
To draw a parabola. Having given the coördinates *a b* and *b c*, to draw a parabola, complete the rectangle *a b c d*. Divide *b c* and *c d* into the same number of equal parts. From *1′*, *2′*, *3′*, etc., draw lines through *a*. Through *1*, *2*, *3*, etc., draw lines parallel to *a b*. The intersections of *1′ a* and *1–1″*, of *2′ a* and *2–2″*, etc. are points on the required parabola.



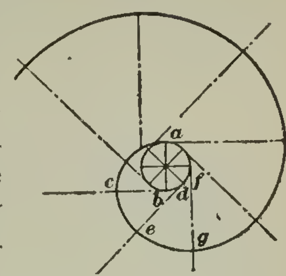
To draw a hyperbola. Having given the coördinates *a b* and *b c*, to draw the curve. Complete the rectangle *a b c d*, and divide *b c* and *c d* into the same number of equal parts. Select any point *e* on the line *b a* prolonged; as *e* is taken farther from *a*, the hyperbola will approach a parabola in form. Connect *1*, *2*, *3* to *e*, and *1′*, *2′*, *3′* to *a*. The intersections of *1e* and *1′a*, of *2e* and *2′a*, etc. are points on the required hyperbola.



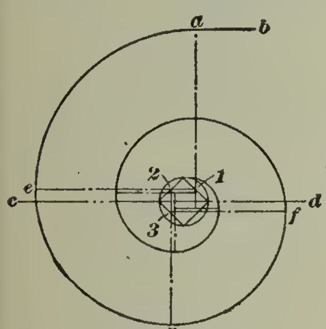
To draw a spiral. From a point, as *o*, draw radiating lines, *o a*, *o b*, *o c*, etc., making equal angles with each other. At any point, as *d*, on *o a*, start the spiral by drawing *d e* perpendicular to *o a*; from *e* where *d e* intersects *o b*, draw *e f* perpendicular to *o b*; etc. By making the angle between the lines smaller, the spiral may be made to make more turns, and the broken line will approach more nearly to a curve.



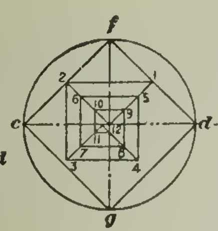
To draw a spiral, second method. Draw a small circle, as bfa. Divide the circumference into any number of equal parts, eight or more. Draw tangents at the points of division, as bc, de, etc. With b as a center, and ba as a radius, strike the arc ac. With d as a center, and dc as a radius, strike the arc ce, etc. This method is a very close approximation, though not mathematically correct.



The Roman Ionic volute. For the *eye*, draw the small circle, taking $\frac{1}{4}$ the distance between ab and cd, in (b), as its diameter. In (a) is shown the eye enlarged. Mark points *1* and *2*, at the middle of fc and fd. Divide *2–12* into three parts by points *6* and *10*. At a distance below cd equal to $2\frac{1}{2}$ times the space between *2–1* and *6–5*, draw *3–4*. Draw *1–12*, *10–9*, *2–3*, and *5–4*. Draw 45° lines from *3* and *4*; draw *6–7*, *10–11*, *9–8*, *11–12*, and *7–8*. Use the points thus found as centers, *1* being the center for arc ae; *2* for arc eg; *3* for arc gf; etc.

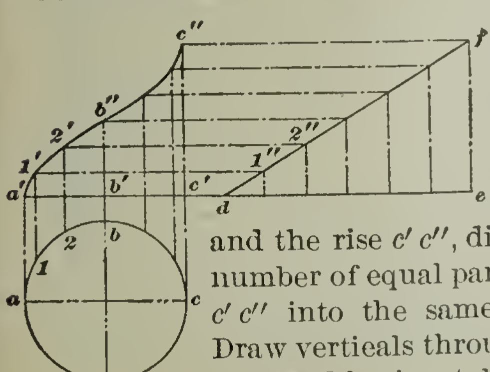


(b)



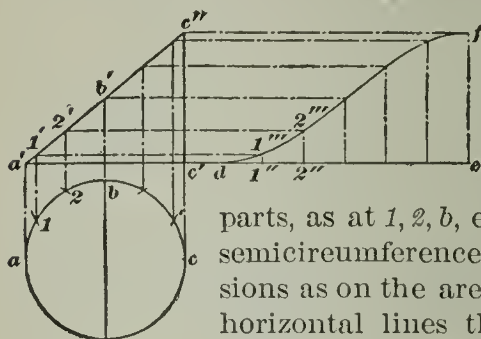
(a)

To draw a helix. A *helix* is the curve assumed by a straight line, as df, drawn on a plane, when the plane is wrapped around a cylindrical surface. To draw a helix, having given the plan of the cylinder abc and the rise $c'c''$, divide the arc abc into any number of equal parts, as at *1*, *2*, b, etc. Divide $c'c''$ into the same number of equal parts. Draw verticals through the divisions of the arc abc, and horizontals through the divisions of



$c' c''$, intersecting in points $1'$, $2'$, b'', etc. Other points may be similarly found and the curve drawn.

To develop the surface of a cylinder cut by a plane oblique to the axis. Let $a b c$ be the plan of the cylinder, and $a' e''$ the inclination of the cutting plane. Divide the arc $a b c$ into any number of equal parts, as at $1, 2, b$, etc. Draw $d e$ equal to the semicircumference, and mark the same divisions as on the arc, as $d\,1''$, $1''$–$2''$, etc. Draw horizontal lines through points $1'$, $2'$, etc., intersecting verticals drawn through $1''$, $2''$, etc., as shown. Trace a curve through the points d, $1'''$, $2'''$, etc., and the figure $d f e$ will be the development of the half cylinder $a b c$.



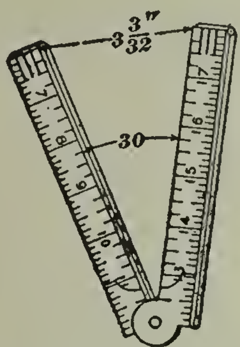
LAYING OUT ANGLES.

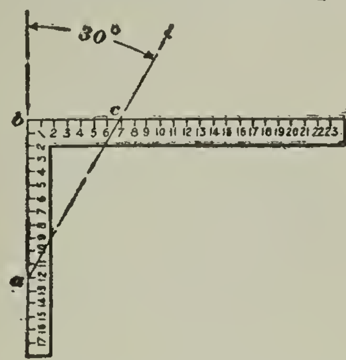
By Two-Foot Rule.—To lay off any angle given in the table, open the rule at the middle until the distance between the inside corners at the knuckle joints (6-inches' mark) is equal to the distance given for that angle under *Chord.*

Degrees.	Chord. Inches.	Degrees.	Chord. Inches.
5	$\frac{17}{32}$	50	$5\frac{1}{16}$
10	$1\frac{1}{32}$	55	$5\frac{17}{32}$
15	$1\frac{9}{32}$	60	6
20	$2\frac{3}{32}$	65	$6\frac{7}{16}$
25	$2\frac{9}{32}$	70	$6\frac{7}{8}$
30	$3\frac{3}{32}$	75	$7\frac{5}{16}$
35	$3\frac{19}{32}$	80	$7\frac{23}{32}$
40	$4\frac{3}{32}$	85	$8\frac{1}{8}$
45	$4\frac{19}{32}$	90	$8\frac{1}{2}$

To lay off an angle greater than 90°, subtract the angle from 180°; lay out the latter angle, extending one side, so that the greater angle formed will be the one required.

By Steel Square.—To lay off any angle given in the table, set either blade or tongue of the square along the line *a b*, marking the 12″ point at *a*. Mark *c* at a distance from *b* equal to





that given in the table for the required angle, and draw *a c*; then the angle *b a c* will be the angle sought, approximately correct.

For example, to find an angle of 30°, the distance *b c* is $6\frac{15}{16}$ in.

Angle. Degrees.	Distance. Inches.	Angle. Degrees.	Distance. Inches.
5	$1\frac{1}{16}$	33° 42′ (⅓ pitch)	8
10	$2\frac{3}{32}$	35	$8\frac{13}{32}$
15	$3\frac{7}{32}$	40	$10\frac{1}{16}$
18° 25′ (⅙ pitch roof)	4	45 (½ pitch)	12
20	$4\frac{3}{8}$	50	$14\frac{5}{16}$
22½	$4\frac{31}{32}$	53° 7′ (⅔ pitch)	16
25	$5\frac{19}{32}$	55	$17\frac{1}{8}$
26° 33′ (¼ pitch)	6	60	$20\frac{25}{32}$
30	$6\frac{15}{16}$		

TAKING *a* AT THE 3″ MARK.

65	$6\frac{7}{16}$	75	$11\frac{3}{16}$
67½ (Octagon Cut)	$7\frac{1}{4}$	80	17
70	$8\frac{1}{4}$	90	Angle *a b c*

STRUCTURAL DESIGN.

LOADS ON STRUCTURES.

Loads on buildings may be classed under three general divisions: *dead* loads, *live* loads, and *snow* and *wind* loads.

DEAD LOADS.

The dead loads consist of the weight of the materials composing the structure. For instance, the brickwork in the walls forms a portion of the dead load upon the footings; the materials in the floors impose a dead load upon the columns, etc. In order to figure the amount of the dead loads on structures and the members therein, the weight of the various materials used must be known, and the following tables will be found useful. (For weights of metals, masonry, woods, etc., see pages 29, 30, and 31.)

TABLE I.

APPROXIMATE WEIGHT OF BUILDING MATERIALS.

Material.	Average Weight. Lb. per Sq. Ft.
Corrugated galvanized iron, No. 20, unboarded	$2\frac{1}{4}$
Copper, 16 oz., standing seam	$1\frac{1}{4}$
Felt and asphalt, without sheathing	2
Glass, $\frac{1}{8}$ in. thick	$1\frac{3}{4}$
Hemlock sheathing, 1 in. thick	2
Lead, about $\frac{1}{8}$ in. thick	6 to 8
Lath-and-plaster ceiling (ordinary)	6 to 8
Mackite, 1 in. thick, with plaster	10
Neponset roofing felt, 2 layers	$\frac{1}{2}$
Spruce sheathing, 1 in. thick	$2\frac{1}{2}$
Slate, $\frac{3}{16}$ in. thick, 3 in. double lap	$6\frac{3}{4}$
Slate, $\frac{1}{8}$ in. thick, 3 in. double lap	$4\frac{1}{2}$
Shingles, $6'' \times 18''$, $\frac{1}{3}$ to weather	2
Skylight of glass, $\frac{3}{16}$ to $\frac{1}{2}$ in., including frame	4 to 10
Slag roof, 4-ply	4
Tin, IX	$\frac{3}{4}$
Tiles (plain), $10\frac{1}{2}'' \times 6\frac{1}{4}'' \times \frac{5}{8}'' - 5\frac{1}{4}''$ to weather	18
Tiles (Spanish), $14\frac{1}{2}'' \times 10\frac{1}{2}'' - 7\frac{1}{4}''$ to weather	$8\frac{1}{2}$
White-pine sheathing, 1 in. thick	$2\frac{1}{2}$
Yellow-pine sheathing, 1 in. thick	4

Where only the approximate dead load due to the weight of floor, partition, or roof construction is desired, the following table will be of use. In this table the wooden floors and roof sheathing are taken as 1 in. thick.

TABLE II.

WEIGHT OF FLOORS, PARTITIONS, AND ROOFS.

Material.	Weight. Lb. per Sq. Ft.
Floors, including weight of beams—	
Wooden, in dwellings	10–15
Wooden, office buildings	25–30
Hollow-tile arch	70–90
Brick and concrete (broken stone)	100–130
Partitions—	
Wooden	15–20
Hollow tile	15–30
Roofs, including framing—	
Shingle	6–10
Tin	6– 8
Slate	12–15
Tar and gravel	10–12
Corrugated iron	8–10
Tile	20–30

NOTE.—If roofs are plastered underneath, add 6 pounds per square foot to the weight given.

In calculating the dead loads, there are certain weights which must be assumed. For instance, the weight of the floorbeams and girders are not known, because their size has not as yet been determined; likewise, the dimensions of the columns and many other structural details are unknown. The assumed weights are obtained by approximating the dimensions of the parts of the structure and estimating their weights. After the structure has been designed, the actual dead loads should be checked, to make sure they approximate closely to those assumed. If any considerable variation is found, it can be taken care of by increasing or diminishing the sizes already determined.

Weight of Fireproof Floors.—In figuring the dead load for any system of floor construction, it is necessary to carefully calculate the total weight of the elements composing the system, which are the arches, filling, flooring, ceiling, and the steel construction. The weight of fixed or permanent partitions should always be taken into account, and the beams, etc. carrying them, proportioned accordingly. Where the partitions are movable, an additional weight of, say, 20 lb. per sq. ft., should be added to the dead load on the entire floor area. The finished floor line is usually considered as being 3 in. above the top of the **I** beams, and the ceiling line as 2 in. below the bottom of them. Cinder concrete filling, which is the usual backing for fireproof arch construction, averages in weight, when dry, 72 lb. per cu. ft., but is sometimes assumed to weigh only 48 lb. per cu. ft.

The weight of the various systems of fireproof floors vary from 60 lb. to 125 lb. per sq. ft. of floor surface, including the steel used; generally, however, a load of 80 lb. per sq. ft. will be sufficient for all economical fireproof floors.

TABLE III.

APPROXIMATE WEIGHT OF FIREPROOF FLOORS.
(*Exclusive of Partitions.*)

Depth of **I** Beams.	Weight. Lb. per Sq. Ft. Including Beams.	
	Brick Arch.	Hollow Tile.
8	74	63– 74
9	74	65– 80
10	81	68– 81
12	94	71– 93
15	113	91–113

Semi-fireproof floors, supported upon **I** beams placed 5 ft. apart crossed every 4 ft. with heavy **T**'s, constructed of buckled plates $\frac{1}{4}$ in. thick and covered with 6 in. of concrete composed of broken stone and cement, imbedding sleepers to which 1 in. finished floor is secured, weigh, approximately 95 lb. per sq. ft.

TABLE IV.

WEIGHT OF FIREPROOFING MATERIALS.

Kind.	Span. Ft.	Thickness. In.	Weight. Lb. per Sq. Ft.
Dense-tile flat arch	4– 7	6–12	22–42
Porous-tile flat arch	3–10	6–15	21–43
Dense-tile partition		3– 6	15–28
Porous-tile partition		3– 6	14–27
Porous-tile ceiling		2– 4	12–20
Porous-tile roofing		2– 4	12–20

LIVE LOADS.

The live load is variable, and consists of the weight of people, furniture, stocks of goods, machinery, etc. The amount of this load, which should be added to the dead load, depends upon the use to which the building is to be put. Where the floor is required to support a considerable live load, concentrated at a particular place, such as a heavy safe or piece of machinery, special provision should be made in the floor construction for it. Table V gives the live loads per square foot recommended as good practice in conservative building construction.

TABLE V.

Live Loads.	Lb. per Sq. Ft.
Dwellings, offices, hotels, and apartment houses	From 40 to 70
Theaters, churches, ballrooms, and drill halls	From 80 to 120
Factories	From 150 up
Warehouses	From 150 to 250

A live load of 70 lb. per sq. ft. will seldom be attained in dwellings; but, as city houses are liable to be used for other than dwelling purposes, it is not generally advisable to

use a lighter load. In country houses, hotels, etc., where economy demands it, and the intended use for a long time is certain, a live load of 40 lb. per sq. ft. of floor surface is ample for all rooms not used for public assembly. For such rooms, a live load of 80 lb. per sq. ft. will usually be sufficient, as experience shows that a floor cannot be crowded more than this. If the desks and chairs are fixed, as in a schoolroom or church, a live load over 40 to 50 lb. will never be attained.

Office-building floors have been designed for a live load ranging from 20 to 150 lb. per sq. ft., but a conservative practice is to use about 70 lb. per sq. ft. An investigation of the live loads in over 200 office buildings in Boston showed that the greatest live load in any office was 40 lb. per sq. ft., while the 10 heaviest loaded offices averaged 33 lb. per sq. ft., the average live load for the entire number of offices being about 17 lb. per sq. ft.

Retail stores should have floors proportioned for a live load of 100 lb. and upwards; while, for wholesale stores, machine shops, etc., a live load of at least 150 lb. per sq. ft. should be figured on. The static load in factories seldom exceeds 40 to 50 lb. per sq. ft. of floor surface, and usually a live load of 100 lb., including the effect of vibrations due to moving machinery, is ample. The conservative rule is, in general, to assume loads not less than the above, and to be sure that the beams are proportioned to avoid excessive deflection. Stiffness is a factor as important as mere strength.

In designing the floors of office or buildings of like character, it is good practice to figure the full live load on the floor joists or beams, but to consider only a certain percentage as coming upon the girders, columns, and foundations, on the assumption that all of the floors will not be fully loaded at the same time. This percentage should be carefully considered in each case; and the amounts will depend upon the height of the building in question and the judgment of the designer.

In proportioning the foundations of hotels, office buildings, etc., the live load may be neglected, but should be considered in heavy warehouses. In buildings carrying heavy machinery causing much vibration, it is good practice to double the estimated live load.

SNOW AND WIND LOADS.

Data in regard to snow and wind loads are necessary in connection with the design of roof trusses.

Snow Load.—When the slope of a roof is over 12 in. rise per foot of horizontal run, a snow and accidental load of 8 lb. per sq. ft. is ample. When the slope is under 12 in. rise per foot of run, a snow and accidental load of 12 lb. per sq. ft. should be used. The snow load acts vertically, and therefore should be added to the dead load in designing roof trusses. The snow load may be neglected when a high wind pressure has been considered, as a great wind storm would very likely remove all the snow from the roof.

Wind Load.—The wind is considered as blowing in a horizontal direction, but the resulting pressure upon the roof is always taken *normal* (at right angles) to the slope. The wind pressure against a vertical plane depends on the velocity of the wind, and, as ascertained by the U. S. Signal Service at Mt. Washington, N. H., is as follows:

TABLE VI.

Velocity. (Mi. per Hr.)	*Pressure.* (Lb. per Sq. Ft.)	
10	0.4	Fresh breeze.
20	1.6	Stiff breeze.
30	3.6	Strong wind.
40	6.4	High wind.
50	10.0	Storm.
60	14.4	Violent storm.
80	25.6	Hurricane.
100	40.0	Violent hurricane.

The wind pressure upon a cylindrical surface is one-half that upon a flat surface of the same height and width.

Since the wind is considered as traveling in a horizontal direction, it is evident that the more nearly vertical the slope of the roof, the greater will be the pressure, and the more nearly horizontal the slope, the less will be the pressure. Table VII gives the pressure exerted upon roofs of different slopes, by a wind pressure of 40 lb. per sq. ft. on a vertical plane, which is equivalent in intensity to a violent hurricane.

TABLE VII.

WIND PRESSURE ON ROOFS.

Pounds per Square Foot.

Rise. In. per Foot of Run.	Angle With Horizontal.	Pitch. Proportion of Rise to Span.	Wind Pressure Normal to Slope.
4	18° 25′	$\frac{1}{6}$	16.8
6	26° 33′	$\frac{1}{4}$	23.7
8	33° 41′	$\frac{1}{3}$	29.1
12	45° 0′	$\frac{1}{2}$	36.1
16	53° 7′	$\frac{2}{3}$	38.7
18	56° 20′	$\frac{3}{4}$	39.3
24	63° 27′	1	40.0

In addition to wind and snow loads upon roofs, the weight of the principals or roof trusses, including the other features of the construction, should be figured in the estimate. For light roofs having a span of not over 50 ft., and not required to support any ceiling, the weight of the steel construction may be taken at 5 lb. per sq. ft.; for greater spans, 1 lb. per sq. ft. should be added for each 10 ft. increase in the span.

STRENGTH OF MATERIALS.

DEFINITIONS OF TERMS.

Stress.—This is the cohesive force by which the particles of a body resist the external load that tends to produce an alteration in the form of the body. Stress is always equal to the effective external force acting upon the body; thus, a bar subjected to a direct pulling force of 1,000 lb. endures a stress of 1,000 lb. *Unit stress* is the stress or load per square inch of section. For instance, if the bar mentioned above is 1 in. × 2 in. in section, the unit stress of the bar would be 1,000 lb. ÷ 2 sq. in. (sectional area) = 500 lb.

Tensile stress is produced when the external forces tend to stretch a body, or pull the particles away from one another.

A rope by which a weight is suspended is an example of a body subjected to tensile stress. *Compressive stress* is produced when the forces tend to compress the body, or push the particles closer together. A post or column of a building is subjected to compressive stress. *Shearing stress* is produced when the forces tend to cause the particles in one section of a body to slide over those of the adjacent section. A steel plate acted on by the knives of a shear, or a beam carrying a load, are subjected to shearing stress. *Transverse* or *bending stress* is produced by loads acting on a beam tending to bend it, and is a combination of tensile, compressive, and shearing stresses.

The *ultimate strength* of any material is that unit stress which is just sufficient to break it. The *ultimate elongation* is the total elongation produced in a unit of length of the material of a unit area, by a stress equal to the ultimate strength of the material.

Strain.—The amount of alteration in form of a body produced by a stress is called *strain*. If a steel wire is subjected to a pulling stress, and is elongated $\frac{1}{10}$ of an in., this alteration is the strain. *Unit strain* is the strain per unit of length or of area. It is usually taken per unit of length, and is called the *elongation* per unit of length. If an iron bar 6 ft. long is subjected to a pulling or tensile force which elongates it 1 in., the unit strain will be 1 in. $\div$ 72 (length of the bar in inches) = .0139 in.

Modulus of Elasticity.—The *modulus* or *coefficient of elasticity* is the ratio between the stresses and corresponding strains for a given material, which may have a somewhat different modulus of elasticity for tension, compression, and shear. If l be the strain or increase per unit length of a material subjected to tensile stress, and p the unit stress producing this elongation, the modulus of elasticity $E = \frac{p}{l}$. For example, a wrought-iron bar, 80 in. long, subjected to a unit tensile stress p of 10,000 lb., stretched .029 in. The unit strain l, or stretch per inch of length, is .029 in. $\div$ 80 in. = .0003625 in.

Then, $$E = \frac{10,000}{.0003625} = 27,586,200.$$

The relation $E = \frac{p}{l}$ is true only when equal additions of stress cause equal increases of strain. Previous to rupture, this condition ceases to exist, and the material is said to be strained beyond the *elastic limit*, which, therefore, is that degree of stress within which the modulus of elasticity is nearly constant and equal to stress divided by strain.

Modulus of Rupture.—The fibers in a beam subjected to transverse stresses are either in compression or tension, but the strength of the extreme fibers agrees neither with their compressive nor tensile strength; hence, in beams of uniform cross-section above and below the neutral axis, a constant determined by actual tests is used. This is called the *modulus of rupture*, and is generally expressed in pounds per square inch.

Factor of Safety.—This is the ratio of the breaking strength of the material to the load imposed upon it, under usual conditions. For instance, if the ultimate strength of an iron tension bar is 50,000 lb., and the load it sustains is 10,000 lb., the factor of safety is 50,000 lb. ÷ 10,000 lb. = 5.

TABLE VIII.

STRENGTH OF METALS IN POUNDS PER SQUARE INCH.

Material.	Ultimate Tensile.	Ultimate Compression.	Ultimate Shearing.	Modulus of Rupture.	Modulus of Elasticity. Millions.
Wrought iron	50,000	44,000	44,000	48,000	27
Shape iron	48,000				26
Structural steel	60,000 65,000	52,000	52,000	60,000	29
Cast iron	18,000	81,000	25,000	45,000	12
Steel, castings	70,000	70,000	60,000	70,000	30
Brass, cast	24,000	*30,000	36,000	20,000	9
Bronze, phosphor	50,000				14
Bronze, aluminum	75,000	120,000			
Aluminum, commercial	15,000	12,000	12,000		11

* Unit stress producing 10% reduction in original length.

TABLE IX.

STRENGTH OF TIMBER IN POUNDS PER SQUARE INCH.

1	2	3	4	5		6	7
Material.	Ultimate Tensile with Grain.	Ultimate Compression Parallel to Grain.	Allowable Com. Perp. to Grain.	Ultimate Shearing.		Modulus of Rupture or Extreme Fiber Stress.	Modulus of Elasticity.
				Parallel to Grain.	Perpendicular to Grain.		
Whiteoak	10,000	4,500	700	800	4,000	6,000	1,100,000
White pine	7,000	3,500	250	400	2,000	4,000	1,000,000
Southern, Long-Leaf, or Georgia yellow pine	12,000	5,000	600	600	5,000	7,000	1,700,000
Douglass, Oregon, and Washington fir or pine { yellow fir	12,000	6,000	400	600		6,500	1,400,000
Douglass, Oregon, and Washington fir or pine { red fir	10,000					5,000	
Northern or Short-Leaf yellow pine	9,000	4,000	350	400	4,000	6,000	1,200,000
Red pine	9,000	4,000	250			5,000	1,200,000
Norway pine	8,000	4,000	250			4,000	1,200,000
Canadian (Ottawa) white pine	10,000	5,000		350			
Canadian (Ontario) red pine	10,000	5,000		400		5,000	1,400,000
Spruce and Eastern fir	8,000	4,000	300	400	3,000	4,000	1,200,000
Hemlock	6,000	4,000	250	350	2,500	3,500	900,000
Cypress	6,000	4,000	250			5,000	900,000
Cedar	8,000	4,000	250		1,500	5,000	700,000
Chestnut	9,000	5,000	350	600	1,500	5,000	1,000,000
California redwood	7,000	4,000	300	400		4,500	700,000
California spruce		4,000				5,000	1,200,000

The values for different woods in Table IX are average values for commercial timber. Column 3 in the table shows the ultimate compressive strength parallel to the grain, which values are used in figuring the ultimate strength of columns. Column 4 gives the allowable compressive strength perpendicular to the grain, the values given being the load per square inch of section required to produce an indenture of $\frac{1}{100}$ of an inch. Reference to Fig. 1 will explain this more clearly.

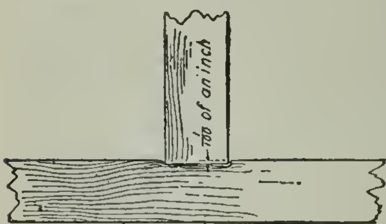


FIG. 1.

The left-hand portion of column 5 will be found of use in calculating the resistance of the timber at the heel of a roof truss. For instance, in Fig. 2, to calculate with what force the piece *c* of the tie member *b* opposes the thrust of the rafter member *a*. The sectional area of the surface *d e f* is 10 in. × 18 in. = 180 sq. in. The ultimate shearing strength of Georgia yellow pine, parallel with the grain, according to Table IX, is 600 lb.; then, 180 × 600 = 108,000 lb., the ultimate strength of the timber. If the safe strength is desired, divide by the required factor of safety; if 4 is used the safe strength will be 108,000 ÷ 4 = 27,000 lb. Column 6, giving the modulus of rupture for different woods, is used in figuring the strength of beams (see page 106).

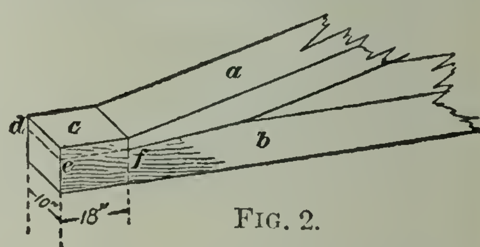


FIG. 2.

From recent tests to determine the physical properties of timber, made by the Forestry Division U. S. Dept. of Agriculture, the following conclusions are deduced: That the bleeding of long-leaf yellow pine, for sap products, is not detrimental to its durability and strength; that moisture reduces the strength of timber, whether that moisture be the sap or that absorbed after seasoning; also, that large timbers are equal in strength to small, provided they are sound and contain the same percentage of moisture.

TABLE X.

AVERAGE ULTIMATE STRENGTH OF MASONRY MATERIALS.

Material.	Compression. Lb. per Sq. In.	Tension. Lb. per Sq. In.	Modulus of Rupture.
Building Stone.			
Bluestone	13,500	1,400	2,700
Granite, average	15,000	600	1,800
Connecticut	12,000		
New Hampshire	15,000		1,500
Massachusetts	16,000		1,800
New York	15,000		
Limestone, average	7,000	1,000	1,500
Hudson River, N. Y.	17,000		
Ohio	12,000		1,500
Marble, Vermont	8,000	700	1,200
Sandstone, average	5,000	150	1,200
New Jersey	12,000		650
New York	10,000		1,700
Ohio	9,000	100	700
Slate	10,000	4,000	5,000
Stonework (strength of stone)	$\frac{4}{10}$	$\frac{4}{10}$	$\frac{4}{10}$
Brick.			
Brick, light red	1,000	40	
Good common	10,000	200	600
Best hard	12,000	400	800
Philadelphia pressed	6,000	200	600
Brickwork, common lime mortar	1,000	50	
Good cement-and-lime mortar	1,500	100	
Best cement mortar	2,000	300	
Terra cotta	5,000		
Terra-cotta work	2,000		
Cements, etc.			
Cement, Rosendale, 1 mo. old	1,200	200	200
Portland, 1 mo. old	2,000	400	400
Rosendale, 1 yr. old	2,000	300	400
Portland, 1 yr. old	3,000	500	800
Mortar, lime, 1 yr. old	400	50	100
Lime and Rosendale, 1 yr. old	600	75	200
Rosendale cement, 1 yr. old	1,000	125	300
Portland cement, 1 yr. old	2,000	250	600
Concrete, Portland, 1 mo. old	1,000	200	100
Rosendale, 1 mo. old	500	100	50
Portland, 1 yr. old	2,000	400	150
Rosendale, 1 yr. old	1,000	200	75

The values in the preceding table are ultimate, and from $\frac{1}{10}$ to $\frac{1}{30}$ of these values is used as the safe working strength of the materials.

The following table gives the safe working loads allowable in good practice for brickwork, masonry, and foundation soils:

TABLE XI.

SAFE BEARING LOADS.

Brick and Stone Masonry.	Lb. per Sq. In.
Brickwork.	
Bricks, hard, laid in lime mortar	100
Hard, laid in Portland cement mortar	200
Hard, laid in Rosendale cement mortar	150
Masonry.	
Granite, capstone	700
Squared stonework	350
Sandstone, capstone	350
Squared stonework	175
Rubble stonework, laid in lime mortar	80
Rubble stonework, laid in cement mortar	150
Limestone, capstone	500
Squared stonework	250
Rubble, laid in lime mortar	80
Rubble, laid in cement mortar	150
Concrete, 1 Portland, 2 sand, 5 broken stone	150
Foundation Soils.	**Tons per Sq. Ft.**
Rock, hardest in native bed	100 —
Equal to best ashlar masonry	25–40
Equal to best brick	15–20
Clay, dry, in thick beds	4– 6
Moderately dry, in thick beds	2– 4
Soft	1– 2
Gravel and coarse sand, well cemented	8–10
Sand, compact and well cemented	4– 6
Clean, dry	2– 4
Quicksand, alluvial soils, etc.	.5– 1

PROPERTIES OF SECTIONS.

CENTER OF GRAVITY.

The center of gravity of a figure or body is that point upon which the figure or body will balance in whatever position it may be placed, provided it is acted upon by no other force than gravity.

If a plane figure is alike or symmetrical on both sides of a center line, the latter line is termed an *axis of symmetry*, and the *center of gravity lies in this line.* If the figure is symmetrical about any other axis, *the intersection of the two axes will be the center of gravity of the section.* Thus, the center of gravity of a square, rectangle, or other parallelogram is at the intersection of the diagonals; of a circle or ellipse, at the center of figure; etc. The center of gravity of a triangle is found at the intersection of lines drawn from the middle of each side to the opposite apex; or, it is $\frac{2}{3}$ the distance from any apex to the middle of the opposite side. For any section, the center of gravity may be found by the principles explained in the following article on *Neutral Axis.* It may be determined approximately, but simply, by drawing to scale upon cardboard the outline of the section; then, by cutting out the figure, and balancing it in different directions on a knife edge, the center of gravity will be at the intersection of the lines on which the section balances.

NEUTRAL AXIS.

When a simple beam is loaded, there is always compression in the topmost fibers and tension in the bottommost fibers. There must, therefore, be a certain position in the cross-section at which the fibers are neither in compression nor tension—that is, they are *neutral;* hence the position of these neutral fibers is called the *neutral axis* of the section. The neutral axis of a beam section passes through the *center of gravity* of the section, and at right angles to the direction in which the loads act. If the section of the beam is symmetrical its axis of symmetry will be a neutral axis, provided

it is perpendicular to the line of action of the loads. By finding the center of gravity of a cardboard pattern, the neutral axis of any section may be located.

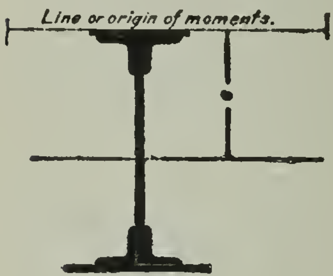


FIG. 3.

For simple sections, such as rectangles, triangles, etc., the required neutral axis is found by the foregoing principles. When, however, the section is made up of combinations of rectangles, etc., as in Fig. 3, the distance c of the neutral axis from any line or origin of moments (usually taken at an edge of the section) may be calculated as follows:

Rule.—*Find the sum of the products of the area of each elementary section multiplied by the perpendicular distance between its center of gravity and the line or origin of moments; divide this sum by the total area of the figure; the result will give the required distance c.*

EXAMPLE.—The distance c, in Fig. 4, is thus found; the line or origin of moments being taken at the line $a\,b$:

1	2	3	4	5
Elementary Section.	Dimensions. Inches.	Area. Sq. In.	Distance From $a\,b$ to Center of Gravity. Inches.	Products. Col. 3 × Col. 4.
Upper plate	8″ × ½″	4.00	.25	1.00
2 upper angles...	* 3″ × 3″ × ⅝″	3.56 × 2	† 1.53	10.89
Web-plate	18″ × ½″	9.00	9.50	85.50
2 lower angles...	3½″ × 3½″ × ⅝″	3.98 × 2	17.40	138.50
Lower plate	12″ × ½″	6.00	18.75	112.50
Totals		34.08		348.39

* For areas, see table, page 85. For decimal equivalents of fractions of inches, see page 53. † See table, page 85.

Therefore, distance c of neutral axis (and center of gravity) from $ab = 348.39 \div 34.08 = 10.22$ in.

By finding another neutral axis in similar manner, the intersection of the two axes will be the center of gravity of the section. If the section, as in Fig. 4, is symmetrical about a vertical axis, the intersection of this axis and the neutral axis will be the center of gravity.

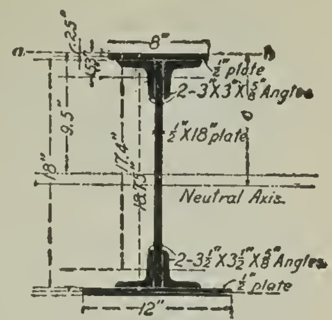


FIG. 4.

MOMENT OF INERTIA.

When a beam is subjected to loading, as in Fig. 5, the fibers of the beam tend to resist the compression at the top and the tension at the bottom, each fiber exerting a force or moment directly proportional to the distance it is located from the neutral axis (provided the elastic limit of the material is not exceeded); hence, the topmost and bottommost fibers are of considerably more value than those located near the neutral axis. It is therefore necessary, before the strength of any section can be obtained, to ascertain the average value of all the fibers in the section; this value is called the *moment of inertia.*

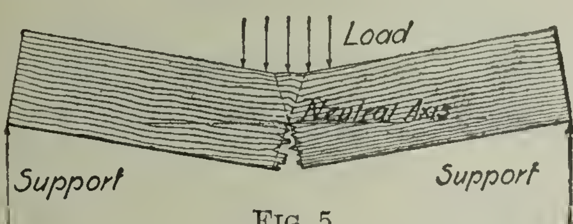


FIG. 5.

The moment of inertia (usually designated by the letter I) of any body or figure is the sum of the products of each particle of the body or elementary area of the figure multiplied by the square of its distance from the axis around which the body would rotate. This axis is the neutral axis.

For example, assuming that the section shown in Fig. 6 is 3 in. $\times$ 12 in., and that it is divided into 36 equal parts, each having an area of 1 sq. in., the approximate moment of inertia may be calculated as follows:

Fibers b, b, b, b, b, b	$= 6$ sq. in. $\times 5.5 \times 5.5 =$	181.50
Fibers c, c, c, c, c, c	$= 6$ sq. in. $\times 4.5 \times 4.5 =$	121.50
Fibers d, d, d, d, d, d	$= 6$ sq. in. $\times 3.5 \times 3.5 =$	73.50
Fibers e, e, e, e, e, e	$= 6$ sq. in. $\times 2.5 \times 2.5 =$	37.50
Fibers f, f, f, f, f, f	$= 6$ sq. in. $\times 1.5 \times 1.5 =$	13.50
Fibers g, g, g, g, g, g	$= 6$ sq. in. $\times .5 \times .5 =$	1.50
	I, or moment of inertia $=$	429.00

In this manner the approximate moment of inertia for any section may be obtained. Table XII, page 83, gives convenient formulas by which the moment of inertia for usual sections may be determined. For instance, according to this table, the formula for the moment of inertia of any rectangular section is $I = \frac{b\,d^3}{12}$, in which b is the breadth of the beam, and d the depth. Thus, the moment of inertia for the section shown in Fig. 6 may be found as follows:

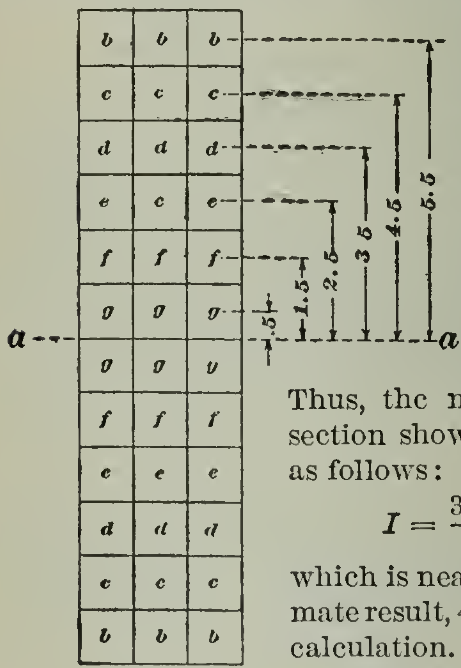


FIG. 6.

$$I = \frac{3 \times 12 \times 12 \times 12}{12} = 432,$$

which is nearly the same as the approximate result, 429, obtained in the previous calculation.

Tables XIII to XIX, on pages 84 to 90, give the moment of inertia for rolled steel sections, and will be found useful in designing structural steel work.

As beam or column sections are often made up of several elementary sections, the moment of inertia is then found thus:

Rule.—*The moment of inertia is equal to the sum of the products of each elementary area multiplied by the square of its distance from the neutral axis, plus its moment of inertia about a parallel axis through its center of gravity.*

If i represents the moment of inertia of each elementary figure, a the area of each, d^2 the square of the perpendicular distance from the center of gravity of each elementary section to the neutral axis $a\,b$, Fig. 7, and I the required moment of inertia, the rule may be expressed thus: $I = \Sigma\,(a\,d^2 + i)$.

Example.—The moment of inertia of the section shown in Fig. 4 may be found as follows, the figure being redrawn with the neutral axis located by the distance c, obtained from calculations on page 77, and shown in Fig. 7.

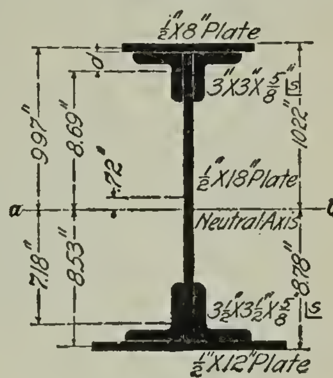


Fig. 7.

Solution.—First work out the formula $a\,d^2 + i$ for each elementary section, as in the following table.

Elementary Section.	Area a. Sq. In.	d. In.	d^2.	i.	$a\,d^2 + i$.
Upper plate	4.00	9.97	99.4	*.0833	397.68
2 upper angles	†3.56×2	8.69	75.51	†3.20×2	544.03
Web-plate	9.00	.72	.5184	243.00	247.66
2 lower angles	3.98×2	7.18	51.55	4.33×2	418.99
Lower plate	6.00	8.53	72.76	.125	436.68

Moment of inertia of section, $I = \Sigma\,(a\,d^2 + i) = 2{,}045.04$.

Graphical Method.—The location of the neutral axis and the moment of inertia of any section may be obtained by the following graphical method, which is sufficiently accurate for all practical purposes.

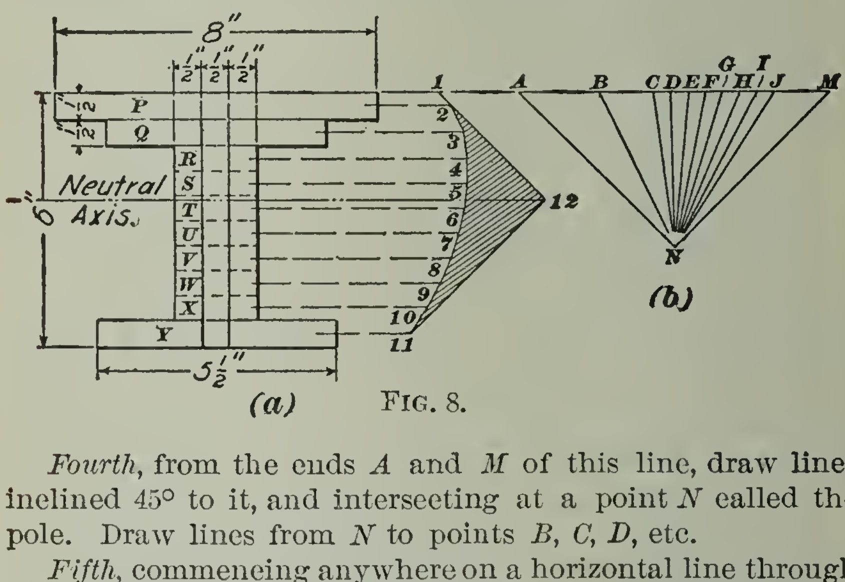
Example.—Locate the neutral axis, and find the moment of inertia of the section shown at (a), Fig. 8.

Solution.—*First*, draw the section, either full size or to any scale, as at (a).

* Figured by formula $\frac{b\,d^3}{12}$, on page 83. † See page 85.

Second, divide this section by horizontal lines into strips of equal or unequal height; find the area in square inches and the center of gravity of each strip; since the strips in this case are rectangles, the centers of gravity will be at the centers of the strips, through which points dot-and-dash lines have been drawn.

Third, on any horizontal line lay off, from left to right, to any scale, distances proportional to the area of the strips, taking them in order from top to bottom of the section. This horizontal line may be called the *load* or *area* line. Thus, at (*b*), the distances *A B*, *B C*, *C D*, etc. are measured to a scale of, say, $\frac{1}{16}$ in. to 1 sq. in. area, and represent the areas of the sections *P*, *Q*, *R*, etc., respectively, in (*a*).



(*a*) FIG. 8.

Fourth, from the ends *A* and *M* of this line, draw lines inclined 45° to it, and intersecting at a point *N* called the pole. Draw lines from *N* to points *B*, *C*, *D*, etc.

Fifth, commencing anywhere on a horizontal line through the top of the section, draw the line *1–2* parallel with the 45° line *A N*; from the intersection of this line with one through the center of gravity of slice *P*, draw *2–3* parallel with *B N*; from the intersection of *2–3* with the horizontal line passing through the center of gravity of slice *Q*, draw the line *3–4* parallel to *C N*. Continue in this manner, drawing the remaining lines *4–5*, *5–6*, etc., parallel, respectively, to *D N*, *E N*, etc.

Sixth, draw, from the points *1* and *11* at the end of the curve, 45° lines intersecting at the point *12*, through which

draw a horizontal line, cutting the section as shown at (a), Fig. 8; this line will be the *neutral axis* of the figure.

Seventh, the moment of inertia I may be found by multiplying the area * in square inches of the seetion-lined figure by the entire area of the section. Thus, if in this ease the area of the former is 4.67 sq. in., and that of the section at (a) is 16.25 sq. in., the moment of inertia will be equal to 16.25 sq. in. $\times$ 4.67 sq. in. $=$ 75.88, the value of I for this section.

RADIUS OF GYRATION.

This term, like moment of inertia, is the expression of a certain value of any section, and is one of the factors in the prineipal column formulas for determining the strength of cast-iron and steel eolumns.

Rule.—*The radius of gyration (R) of any section is equal to the square root of the quotient obtained by dividing the moment of inertia† of the section (I) by the area of the section (A).*

The rule may be thus expressed by formula:

$$R = \sqrt{\frac{I}{A}}; \text{ or, } R^2 = \frac{I}{A}.$$

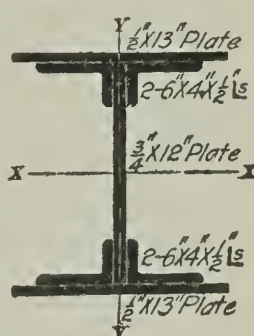


FIG. 9.

For convenient formulas to obtain the radius of gyration of usual sections, see Table XII, page 83. For the radius of gyration of rolled shapes, see tables on pages 84 to 93.

EXAMPLE.—What is the *least* radius of gyration of the structural steel-column section shown in Fig. 9?

SOLUTION.—The value of I, or moment of inertia (found by one of the methods given on pages 78 to 80), on the axis XX, is equal to 1,129, while on the axis YY it is equal to 366.1. The seetional area is 41.44 sq. in. Using the least value of I, there results,

$$R = \sqrt{\frac{366.1}{41.44}}, \text{ or } 2.97.$$

* To find area of irregular figures, see page 36. In obtaining dimensions necessary for determining the area, the same scale should be adopted as used in laying out the section at (a), Fig. 8. † See pages 77 to 81.

SECTION MODULUS, OR RESISTING INCHES.

The *section modulus*, or, as it is sometimes called, *resisting inches*, of a section is *equal to the moment of inertia divided by the greatest distance of* the *neutral axis from the outside fibers* of the figure or section. This rule expressed in formula would be,

$$Q = \frac{I}{c},$$

where, Q = section modulus;
I = moment of inertia * of the section;
c = greatest distance from the outside fiber to the neutral axis †.

EXAMPLE.—What is the section modulus for the cross-section of a $3'' \times 12''$ joist?

SOLUTION.—Since the cross-section is rectangular, the neutral axis must pass through the center of the section, and the distance c is in this case equal to one-half the depth, that is, 6 in. The moment of inertia may be found by the method given on page 77; or more easily by the formula for rectangular sections given in Table XII, on page 83. This formula is $I = \frac{b\,d^3}{12}$, where b = the breadth, and d = the depth of the joist.

Then, $$I = \frac{3 \times 12 \times 12 \times 12}{12}, \text{ or } 432.$$

Having found the value of c and I, they may be substituted in the formula for obtaining the section modulus, and

$$Q = \frac{I}{c} = \frac{432}{6} = 72,$$

which is the section modulus, or resisting inches, for a $3'' \times 12''$ joist.

Formulas for obtaining directly the section modulus of the usual sections are given in Table XII, page 83. The section modulus is given for the usual rolled structural sections in the tables on pages 84 to 90.

These latter are especially convenient as by them sections of different dimensions can be readily compared, and the most economical selected.

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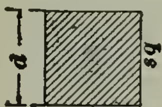
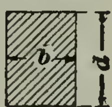
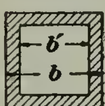
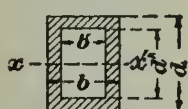
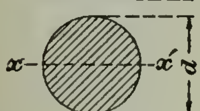
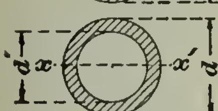
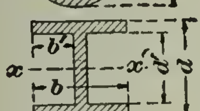
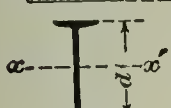
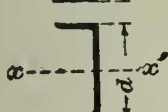
* See page 77. † See page 76.

TABLE XII.

Shape of Section.	Moment of Inertia. I.	Section Modulus. Q.	Sq. Least Radius of Gyration. R^2.
	$\frac{d^4}{12}$	$\frac{d^3}{6}$	$\frac{d^2}{12}$
	$\frac{b\,d^3}{12}$	$\frac{b\,d^2}{6}$	$\frac{b^2}{12}$
	$\frac{b^4 - b'^4}{12}$	$\frac{I}{.5b}$	$\frac{b^2 + b'^2}{12}$
	$\frac{b\,d^3 - b'\,d'^3}{12}$	$\frac{I}{.5d}$	$\frac{I}{A}$
	$\frac{\pi\,d^4}{64}$, or $.0491 d^4$	$\frac{\pi\,d^3}{32}$, or $.0982\,d^3$	$\frac{d^2}{16}$
	$.0491\,(d^4 - d'^4)$	$.0982\left(d^3 - \frac{d'^4}{d}\right)$	$\frac{d^2+d'^2}{16}$
	$\frac{b\,d^3 - 2\,b'\,d'^3}{12}$	$\frac{I}{0.5\,d}$	$\frac{I}{A}$
	$\frac{A\,d^2}{6.66}$ (Approx.)	$\frac{A\,d}{3.2}$ (Approx.)	$\frac{I}{A}$
	$\frac{A\,d^2}{7.34}$ (Approx.)	$\frac{A\,d}{3.67}$ (Approx.)	$\frac{I}{A}$

NOTE.—A = total area of section. In calculating the *least* radius of gyration be sure to use the *least* moment of inertia. $x\,x'$ denotes the neutral axis, and the value of I given is that about this axis.

TABLE XIII.

PROPERTIES OF STEEL CHANNELS.

Depth of Channel.	Weight per Foot.	Area.	Thickness of Web.	Width of Flange.	Neutral Axis Perpendicular to Web at Center. Moment of Inertia.	Section Modulus.	Radius of Gyration. Inches.	Neutral Axis Parallel to Back of Channel. Moment of Inertia.	Radius of Gyration. Inches.	Center of Gravity From Back.
In.	Lb.	Sq. In.	In.	In.	*I.*	*Q.*	*R.*	*I'.*	*R'.*	In.
15	50	14.71	.72	3.72	402.70	53.70	5.23	11.220	.87	.80
15	40	11.80	.47	3.63	371.60	49.50	5.62	11.500	.99	.89
15	33	9.70	.40	3.38	304.20	40.50	5.64	7.900	.92	.79
12	40	11.76	.76	3.42	197.00	32.80	4.09	6.630	.75	.72
12	27	7.90	.38	3.13	161.00	26.80	4.54	5.730	.86	.78
12	20	5.90	.28	2.88	124.70	20.80	4.59	3.690	.79	.69
10	30	8.82	.68	3.04	103.20	20.60	3.42	3.990	.67	.65
10	20	5.90	.31	2.88	85.50	17.10	3.81	3.750	.80	.74
10	15	4.40	.25	2.60	66.82	13.40	3.89	2.490	.74	.66
9	16	4.70	.28	2.56	57.09	12.70	3.48	2.590	.74	.66
9	13	3.80	.23	2.36	45.48	10.10	3.46	1.640	.64	.57
8	13	3.80	.25	2.22	35.56	8.89	3.07	1.470	.62	.58
8	10	3.00	.20	2.08	28.20	7.05	3.08	1.000	.58	.52
7	13	3.80	.28	2.22	27.35	7.81	2.69	1.890	.71	.62
7	9	2.61	.20	2.00	19.05	5.43	2.70	.814	.56	.51
6	17	4.85	.38	2.41	25.43	8.48	2.28	2.390	.70	.78
6	12	3.48	.28	2.19	18.70	6.23	2.32	1.380	.63	.65
6	8	2.35	.20	1.94	12.75	4.25	2.33	.710	.55	.52
5	9	2.59	.25	1.91	9.67	3.87	1.93	.810	.55	.57
5	6	1.76	.18	1.66	6.53	2.61	1.93	.390	.47	.45
4	8	2.31	.27	1.86	5.47	2.73	1.54	.685	.55	.59
4	5	1.46	.17	1.59	3.59	1.80	1.57	.293	.45	.46
3	6	1.76	.36	1.60	2.10	1.40	1.08	.310	.42	.46
3	5	1.47	.26	1.50	1.80	1.20	1.12	.250	.41	.44
3	4	1.19	.17	1.41	1.60	1.10	1.17	.200	.41	.44

TABLE XIV.

PROPERTIES OF STEEL ANGLES—EQUAL LEGS.

Size of Angles.	Thickness.	Weight per Foot.	Area of Section.	Distance from Center of Gravity to Back of Flange.	Moment of Inertia, Axis Parallel to Flange.	Section Modulus, Axis as Before.	Radius of Gyration, Axis as Before.
In.	In.	Lb.	Sq. In.	In.	*I.*	*Q.*	*R.*
6×6	$\frac{7}{8}$	34.00	10.03	1.87	35.300	8.170	1.87
6×6	$\frac{7}{16}$	17.20	5.06	1.66	17.680	4.070	1.87
6×6	$\frac{3}{8}$	14.80	4.36	1.64	15.400	3.520	1.88
5×5	$\frac{3}{4}$	24.20	7.11	1.56	17.000	4.780	1.55
5×5	$\frac{3}{8}$	12.30	3.61	1.39	8.740	2.420	1.56
4×4	$\frac{13}{16}$	20.80	6.11	1.35	9.450	3.320	1.24
4×4	$\frac{5}{16}$	8.16	2.40	1.12	3.720	1.290	1.24
$3\frac{1}{2} \times 3\frac{1}{2}$	$\frac{5}{8}$	13.50	3.98	1.10	4.330	1.810	1.04
$3\frac{1}{2} \times 3\frac{1}{2}$	$\frac{5}{16}$	7.11	2.09	.99	2.450	.980	1.08
3×3	$\frac{5}{8}$	12.10	3.56	1.03	3.200	1.480	.94
3×3	$\frac{1}{4}$	4.90	1.44	.84	1.240	.580	.93
$2\frac{1}{2} \times 2\frac{1}{2}$	$\frac{1}{2}$	7.85	2.31	.82	1.330	.760	.76
$2\frac{1}{2} \times 2\frac{1}{2}$	$\frac{1}{4}$	4.05	1.19	.72	.700	.400	.77
$2\frac{1}{4} \times 2\frac{1}{4}$	$\frac{1}{2}$	7.17	2.11	.78	1.040	.650	.70
$2\frac{1}{4} \times 2\frac{1}{4}$	$\frac{1}{4}$	3.70	1.06	.66	.510	.320	.69
$2\frac{1}{4} \times 2\frac{1}{4}$	$\frac{3}{16}$	2.75	.81	.63	.390	.240	.69
2×2	$\frac{1}{2}$	6.32	1.86	.72	.720	.510	.62
2×2	$\frac{3}{16}$	2.41	.71	.57	.280	.190	.62
$1\frac{3}{4} \times 1\frac{3}{4}$	$\frac{7}{16}$	4.72	1.39	.61	.390	.320	.52
$1\frac{3}{4} \times 1\frac{3}{4}$	$\frac{3}{16}$	2.11	.62	.51	.180	.140	.54
$1\frac{1}{2} \times 1\frac{1}{2}$	$\frac{3}{8}$	3.33	.98	.51	.190	.190	.44
$1\frac{1}{2} \times 1\frac{1}{2}$	$\frac{3}{16}$	1.80	.53	.44	.110	.104	.46
$1\frac{1}{4} \times 1\frac{1}{4}$	$\frac{5}{16}$	2.55	.75	.46	.123	.134	.40
$1\frac{1}{4} \times 1\frac{1}{4}$	$\frac{1}{8}$	1.02	.30	.35	.044	.049	.38
1×1	$\frac{1}{4}$	1.57	.46	.36	.045	.064	.31
1×1	$\frac{1}{8}$	.78	.23	.30	.022	.031	.31
$\frac{7}{8} \times \frac{7}{8}$	$\frac{3}{16}$	.99	.29	.29	.019	.033	.26
$\frac{7}{8} \times \frac{7}{8}$	$\frac{1}{8}$	.68	.20	.25	.014	.022	.27
$\frac{3}{4} \times \frac{3}{4}$	$\frac{3}{16}$	.85	.25	.26	.012	.024	.22
$\frac{3}{4} \times \frac{3}{4}$	$\frac{1}{8}$	.58	.17	.23	.009	.017	.23

TABLE XV.

PROPERTIES OF STEEL ANGLES—UNEQUAL LEGS.

Size of Angle.	Weight per Foot	Area of Section.	Neutral Axis Parallel to Shorter Flange.				Neutral Axis Parallel to Longer Flange.			
			Center of Gravity.*	Moment of Inertia.	Section Modulus.	Rad. of Gyration. (In.)	Center of Gravity.*	Moment of Inertia.	Section Modulus.	Rad. of Gyration. (In.)
Inches.	Lb.	Sq. In.	In.	*I.*	*Q.*	*R.*	In.	*I'.*	*Q'.*	*R'*
$6 \times 4 \times \frac{7}{8}$	28.4	8.34	2.2	31.84	7.89	1.9	1.18	11.81	3.85	1.2
$6 \times 4 \times \frac{3}{8}$	12.3	3.61	1.9	13.51	3.32	1.9	.94	4.90	1.60	1.2
$5 \times 3\frac{1}{2} \times \frac{3}{4}$	20.3	5.98	1.8	15.15	4.53	1.6	1.03	6.23	2.39	1.0
$5 \times 3\frac{1}{2} \times \frac{3}{8}$	10.4	3.05	1.6	7.78	2.29	1.6	.86	3.18	1.21	1.0
$5 \times 3 \times \frac{3}{4}$	19.3	5.68	1.9	14.91	4.55	1.6	.88	4.27	1.85	.9
$5 \times 3 \times \frac{5}{16}$	8.2	2.40	1.7	6.26	1.89	1.6	.68	1.75	.75	.8
$4\frac{1}{2} \times 3 \times \frac{3}{4}$	17.8	5.23	1.7	10.73	3.59	1.4	.91	3.89	1.75	.9
$4\frac{1}{2} \times 3 \times \frac{5}{16}$	7.7	2.25	1.5	4.67	1.54	1.5	.72	1.70	.75	.9
$4 \times 3\frac{1}{2} \times \frac{3}{4}$	17.8	5.23	1.4	8.12	2.95	1.2	1.12	5.83	2.33	1.0
$4 \times 3\frac{1}{2} \times \frac{5}{16}$	7.7	2.25	1.2	3.57	1.24	1.3	.93	2.55	.99	1.1
$4 \times 3 \times \frac{5}{8}$	13.5	3.98	1.4	6.04	2.31	1.2	.87	2.73	1.28	.8
$4 \times 3 \times \frac{5}{16}$	7.1	2.09	1.3	3.38	1.23	1.3	.76	1.65	.74	.9
$3\frac{1}{2} \times 3 \times \frac{5}{8}$	12.5	3.67	1.2	4.11	1.76	1.1	.92	2.75	1.32	.9
$3\frac{1}{2} \times 3 \times \frac{5}{16}$	6.6	1.93	1.1	2.33	.96	1.1	.81	1.58	.72	.9
$3\frac{1}{2} \times 2\frac{1}{2} \times \frac{9}{16}$	10.6	3.13	1.2	3.76	1.62	1.1	.75	1.61	.89	.7
$3\frac{1}{2} \times 2\frac{1}{2} \times \frac{1}{4}$	4.9	1.44	1.1	1.80	.75	1.1	.61	.78	.41	.7
$3 \times 2\frac{1}{2} \times \frac{9}{16}$	9.7	2.84	1.0	2.44	1.21	.9	.79	1.53	.86	.7
$3 \times 2\frac{1}{2} \times \frac{1}{4}$	4.5	1.31	.9	1.17	.56	.9	.66	.74	.40	.8
$3 \times 2 \times \frac{1}{2}$	7.7	2.25	1.1	1.92	1.00	.9	.58	.67	.47	.6
$3 \times 2 \times \frac{1}{4}$	4.1	1.19	1.0	1.09	.54	1.0	.49	.39	.26	.6
$2\frac{1}{4} \times 1\frac{1}{2} \times \frac{5}{16}$	3.6	1.07	.8	.53	.37	.7	.42	.19	.18	.4
$2\frac{1}{4} \times 1\frac{1}{2} \times \frac{3}{16}$	2.3	.67	.8	.34	.23	.7	.37	.12	.11	.4
$2 \times 1\frac{3}{4} \times \frac{5}{16}$	3.6	1.07	.6	.40	.30	.6	.52	.28	.23	.5
$2 \times 1\frac{3}{4} \times \frac{3}{16}$	2.3	.67	.6	.26	.19	.6	.47	.19	.15	.5
$1\frac{3}{8} \times 1\frac{1}{8} \times \frac{5}{16}$	2.5	.72	.5	.13	.15	.4	.38	.08	.10	.3

* Distance measured from outside of flange.

TABLE XVI.

PROPERTIES OF STEEL T SHAPES—EQUAL LEGS.

Size of T. Flange by Stem.	Thickness.	Weight Per Foot.	Area of Section.	Distance of Center of Gravity From Flange.*	Neutral Axis Parallel to Flange. Moment of Inertia.	Neutral Axis Parallel to Flange. Section Modulus.	Neutral Axis Parallel to Flange. Radius of Gyration. Inches.	Natural Axis Square to Flange and Coincident With Stem. Moment of Inertia.	Natural Axis Square to Flange and Coincident With Stem. Section Modulus.	Natural Axis Square to Flange and Coincident With Stem. Radius of Gyration. Inches.
In.	In.	Lb.	Sq. In.	In.	*I.*	*Q.*	*R.*	*I'.*	*Q'.*	*R'.*
4 × 4	$\frac{1}{2}$	13.60	4.00	1.18	5.70	2.02	1.20	2.80	1.40	.84
4 × 4	$\frac{3}{8}$	10.40	3.07	1.15	4.70	1.64	1.23	2.19	1.09	.85
$3\frac{1}{2} \times 3\frac{1}{2}$	$\frac{1}{2}$	11.70	3.45	1.06	3.72	1.52	1.04	1.89	1.08	.74
$3\frac{1}{2} \times 3\frac{1}{2}$	$\frac{7}{16}$	10.40	3.07	1.03	3.35	1.35	1.05	1.65	.94	.73
$3\frac{1}{2} \times 3\frac{1}{2}$	$\frac{5}{16}$	6.80	2.04	.98	2.30	.93	1.09	1.07	.61	.73
3 × 3	$\frac{1}{2}$	10.00	2.94	.93	2.31	1.10	.88	1.20	.80	.64
3 × 3	$\frac{7}{16}$	9.10	2.67	.92	2.12	1.01	.90	1.08	.72	.64
3 × 3	$\frac{3}{8}$	7.80	2.28	.88	1.81	.86	.90	.90	.60	.63
3 × 3	$\frac{5}{16}$	6.60	1.95	.86	1.60	.74	.90	.75	.50	.62
$2\frac{1}{2} \times 2\frac{1}{2}$	$\frac{3}{8}$	6.40	1.89	.76	1.00	.59	.74	.52	.42	.53
$2\frac{1}{2} \times 2\frac{1}{2}$	$\frac{5}{16}$	5.50	1.62	.74	.87	.50	.74	.44	.35	.52
$2\frac{1}{4} \times 2\frac{1}{4}$	$\frac{5}{16}$	4.90	1.44	.69	.66	.42	.68	.33	.30	.48
$2\frac{1}{4} \times 2\frac{1}{4}$	$\frac{1}{4}$	4.10	1.20	.66	.51	.32	.67	.25	.22	.47
2 × 2	$\frac{5}{16}$	4.30	1.26	.63	.45	.33	.60	.23	.23	.43
2 × 2	$\frac{1}{4}$	3.70	1.08	.59	.36	.25	.60	.18	.18	.42
$1\frac{3}{4} \times 1\frac{3}{4}$	$\frac{1}{4}$	3.10	.90	.54	.23	.19	.51	.12	.14	.37
$1\frac{3}{4} \times 1\frac{3}{4}$	$\frac{3}{16}$	2.25	.66	.52	.17	.14	.51	.09	.10	.37
$1\frac{1}{2} \times 1\frac{1}{2}$	$\frac{1}{4}$	2.55	.75	.42	.15	.14	.49	.08	.10	.34
$1\frac{1}{2} \times 1\frac{1}{2}$	$\frac{3}{16}$	1.85	.54	.44	.11	.11	.45	.06	.07	.31
$1\frac{1}{4} \times 1\frac{1}{4}$	$\frac{1}{4}$	2.04	.60	.40	.08	.10	.36	.05	.07	.27
$1\frac{1}{4} \times 1\frac{1}{4}$	$\frac{3}{16}$	1.55	.45	.38	.06	.07	.37	.03	.05	.26
1 × 1	$\frac{3}{16}$	1.23	.36	.32	.03	.05	.29	.02	.04	.21
1 × 1	$\frac{1}{8}$	.90	.26	.29	.02	.03	.29	.01	.02	.21

* Distance measured from outside of flange.

TABLE XVII.

PROPERTIES OF STEEL T SHAPES—UNEQUAL LEGS.

Size of T Flange by Stem.	Thickness.	Weight per Foot.	Area of Section.	Distance of Center of Gravity From Flange.*	Neutral Axis Parallel to Flange.			Neutral Axis Square to Flange and Coincident With Stem.		
					Moment of Inertia.	Section Modulus.	Radius of Gyration in Inches.	Moment of Inertia.	Section Modulus.	Radius of Gyration in Inches.
In.	In.	Lb.	Sq. In.	In.	*I.*	*Q.*	*R.*	*I′.*	*Q′.*	*R′.*
6 × 4	$\frac{5}{8}$	20.6	6.06	1.04	7.66	2.58	1.13	11.50	3.83	1.38
6 × 4	$\frac{1}{2}$	17.0	5.00	.99	6.37	2.11	1.13	9.22	3.07	1.34
5 × 3	$\frac{1}{2}$	13.5	3.97	.75	2.60	1.15	.83	5.23	2.09	1.18
5 × $2\frac{1}{2}$	$\frac{3}{8}$	10.4	3.07	.57	1.24	.64	.64	4.24	1.70	1.18
$4\frac{1}{2}$ × 3	$\frac{3}{8}$	10.0	3.00	.75	2.10	.94	.86	3.10	1.38	1.04
$4\frac{1}{2}$ × 3	$\frac{5}{16}$	8.5	2.55	.73	1.80	.81	.87	2.60	1.16	1.03
4 × $3\frac{1}{2}$	$\frac{1}{2}$	12.5	3.70	1.01	3.97	1.60	1.04	2.88	1.44	.88
4 × $3\frac{1}{2}$	$\frac{3}{8}$	9.8	2.88	.92	3.20	1.24	1.05	2.18	1.09	.87
4 × $2\frac{1}{2}$	$\frac{3}{8}$	8.6	2.52	.63	1.20	.62	.69	2.10	1.05	.92
4 × 2	$\frac{3}{8}$	7.9	2.31	.48	.60	.40	.52	2.12	1.06	.96
$3\frac{1}{2}$ × 4	$\frac{1}{2}$	12.8	3.75	1.25	5.50	1.98	1.21	1.89	1.08	.72
$3\frac{1}{2}$ × 4	$\frac{3}{8}$	9.9	2.91	1.19	4.30	1.55	1.22	1.42	.81	.70
3 × 4	$\frac{1}{2}$	11.9	3.48	1.32	5.23	1.94	1.23	1.21	.81	.59
3 × $3\frac{1}{2}$	$\frac{1}{2}$	10.9	3.21	1.12	3.50	1.49	1.06	1.20	.80	.62
3 × $3\frac{1}{2}$	$\frac{7}{16}$	9.8	2.88	1.11	3.30	1.37	1.08	1.31	.88	.68
3 × $3\frac{1}{2}$	$\frac{3}{8}$	8.5	2.49	1.09	2.90	1.21	1.09	.93	.62	.61
3 × $2\frac{1}{2}$	$\frac{3}{8}$	7.2	2.10	.71	1.10	.60	.72	.89	.60	.66
3 × $2\frac{1}{2}$	$\frac{5}{16}$	6.1	1.80	.68	.94	.52	.73	.75	.50	.65
3 × 2	$\frac{3}{8}$	6.4	1.88	.55	.53	.37	.56	.85	.57	.71
3 × $1\frac{1}{2}$	$\frac{3}{8}$	5.7	1.68	.40	.22	.20	.34	.85	.57	.75
$2\frac{1}{2}$ × 3	$\frac{3}{8}$	7.2	2.10	.97	1.80	.87	.92	.54	.43	.51
$2\frac{1}{2}$ × 3	$\frac{5}{16}$	6.1	1.80	.92	1.60	.76	.94	.44	.35	.51
$2\frac{1}{4}$ × $1\frac{1}{4}$	$\frac{1}{4}$	3.1	.90	.32	.10	.11	.34	.24	.23	.54

* Distance measured from outside of flange.

TABLE XVIII.

PROPERTIES OF STEEL Z BARS.

Depth of Web.	Width of Flange.	Thickness.	Weight per Foot.	Area of Section.	Neutral Axis Perpendicular to Web. Moment of Inertia.	Neutral Axis Perpendicular to Web. Section Modulus.	Neutral Axis Perpendicular to Web. Rad. of Gyration. (In.)	Neutral Axis Coincident With Web. Moment of Inertia.	Neutral Axis Coincident With Web. Section Modulus.	Neutral Axis Coincident With Web. Rad. of Gyration. (In.)
In.	In.	In.	Lb.	Sq. In.	*I.*	*Q.*	*R.*	*I′.*	*Q′.*	*R′.*
6	$3\frac{1}{2}$	$\frac{3}{8}$	15.6	4.59	25.32	8.44	2.35	9.11	2.75	1.41
$6\frac{1}{16}$	$3\frac{9}{16}$	$\frac{7}{16}$	18.3	5.39	29.80	9.83	2.35	10.95	3.27	1.43
$6\frac{1}{8}$	$3\frac{5}{8}$	$\frac{1}{2}$	21.0	6.19	34.36	11.22	2.36	12.87	3.81	1.44
6	$3\frac{1}{2}$	$\frac{9}{16}$	22.7	6.68	34.64	11.55	2.28	12.59	3.91	1.37
$6\frac{1}{16}$	$3\frac{9}{16}$	$\frac{5}{8}$	25.4	7.46	38.86	12.82	2.28	14.42	4.43	1.39
$6\frac{1}{8}$	$3\frac{5}{8}$	$\frac{11}{16}$	28.0	8.25	43.18	14.10	2.29	16.34	4.98	1.41
6	$3\frac{1}{2}$	$\frac{3}{4}$	29.3	8.63	42.12	14.04	2.21	15.44	4.94	1.34
$6\frac{1}{16}$	$3\frac{9}{16}$	$\frac{13}{16}$	32.0	9.40	46.13	15.22	2.22	17.27	5.47	1.36
$6\frac{1}{8}$	$3\frac{5}{8}$	$\frac{7}{8}$	34.6	10.17	50.22	16.40	2.22	19.18	6.02	1.37
5	$3\frac{1}{4}$	$\frac{5}{16}$	11.6	3.40	13.36	5.34	1.98	6.18	2.00	1.35
$5\frac{1}{16}$	$3\frac{5}{16}$	$\frac{3}{8}$	13.9	4.10	16.18	6.39	1.99	7.65	2.45	1.37
$5\frac{1}{8}$	$3\frac{3}{8}$	$\frac{7}{16}$	16.4	4.81	19.07	7.44	1.99	9.20	2.92	1.38
5	$3\frac{1}{4}$	$\frac{1}{2}$	17.8	5.25	19.19	7.68	1.91	9.05	3.02	1.31
$5\frac{1}{16}$	$3\frac{5}{16}$	$\frac{9}{16}$	20.2	5.94	21.83	8.62	1.91	10.51	3.47	1.33
$5\frac{1}{8}$	$3\frac{3}{8}$	$\frac{5}{8}$	22.6	6.64	24.53	9.57	1.92	12.06	3.94	1.35
5	$3\frac{1}{4}$	$\frac{11}{16}$	23.7	6.96	23.68	9.47	1.84	11.37	3.91	1.28
$5\frac{1}{16}$	$3\frac{5}{16}$	$\frac{3}{4}$	26.0	7.64	26.16	10.34	1.85	12.83	4.37	1.30
$5\frac{1}{8}$	$3\frac{3}{8}$	$\frac{13}{16}$	28.3	8.33	29.31	11.44	1.88	14.36	4.84	1.31
4	$3\frac{1}{16}$	$\frac{1}{4}$	8.2	2.41	6.28	3.14	1.62	4.23	1.44	1.33
$4\frac{1}{16}$	$3\frac{1}{8}$	$\frac{5}{16}$	10.3	3.03	7.94	3.91	1.62	5.46	1.84	1.34
$4\frac{1}{8}$	$3\frac{3}{16}$	$\frac{3}{8}$	12.4	3.66	9.63	4.67	1.62	6.77	2.26	1.36
4	$3\frac{1}{16}$	$\frac{7}{16}$	13.8	4.05	9.66	4.83	1.55	6.73	2.37	1.29
$4\frac{1}{16}$	$3\frac{1}{8}$	$\frac{1}{2}$	15.8	4.66	11.18	5.50	1.55	7.96	2.77	1.31
$4\frac{1}{8}$	$3\frac{3}{16}$	$\frac{9}{16}$	17.9	5.27	12.74	6.18	1.55	9.26	3.19	1.33

TABLE XIX.

PROPERTIES OF STEEL I BEAMS.

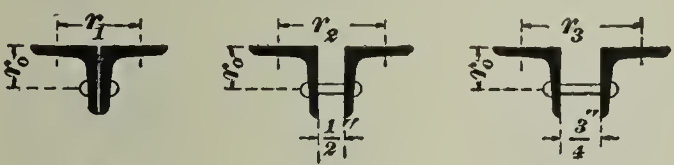
Depth of Beam.	Weight per Foot.	Area.	Thickness of Web.	Width of Flange.	Moment of Inertia. Neutral Axis Square to Web at Center.	Section Modulus. Neutral Axis as Before.	Radius of Gyration. Neutral Axis as Before. Inches.	Moment of Inertia. Neutral Axis Coincident With Center Line of Web.	Radius of Gyration. Neutral Axis as Before. Inches.
In.	Lb.	Sq. In.	In.	In.	*I.*	*Q.*	*R.*	*I'.*	*R'.*
20	90	26.4	.78	6.75	1506.10	150.60	7.55	42.30	1.27
20	80	23.5	.69	6.38	1345.10	134.50	7.55	33.20	1.19
20	75	22.1	.66	6.16	1246.90	124.70	7.53	28.20	1.13
20	65	19.1	.50	6.00	1148.60	114.90	7.76	25.50	1.16
15	75	22.1	.81	6.29	720.40	96.00	5.72	34.60	1.25
15	$66\frac{2}{3}$	19.7	.65	6.13	676.30	90.10	5.87	31.70	1.27
15	60	17.6	.52	6.00	637.70	85.00	6.02	29.20	1.29
15	50	14.7	.45	5.75	529.70	70.60	6.00	21.00	1.20
15	42	12.4	.40	5.50	429.60	57.30	5.90	14.00	1.08
12	55	16.1	.63	6.00	358.10	59.70	4.72	25.20	1.25
12	40	11.8	.39	5.50	281.30	46.90	4.90	16.80	1.20
12	$31\frac{1}{2}$	9.3	.35	5.13	220.50	36.70	4.88	10.30	1.04
10	40	11.8	.58	5.21	178.50	35.70	3.89	13.50	1.07
10	33	9.7	.37	5.00	161.30	32.30	4.08	11.80	1.10
10	30	8.8	.45	4.89	134.50	26.90	3.90	8.10	0.96
10	25	7.3	.31	4.75	122.50	24.50	4.06	7.30	0.99
9	27	7.9	.31	4.75	110.60	24.60	3.72	9.10	1.07
9	$23\frac{1}{3}$	6.9	.35	4.58	89.00	19.80	3.60	5.90	0.93
9	21	6.2	.27	4.50	84.30	18.70	3.70	5.56	0.95
8	27	7.9	.48	4.56	77.60	19.40	3.14	6.91	0.93
8	22	6.4	.29	4.38	69.70	17.40	3.30	6.02	0.97
8	18	5.2	.25	4.13	56.80	14.20	3.30	3.95	0.87
7	20	5.7	.28	4.09	47.60	13.60	2.89	4.86	0.92
7	15	4.4	.23	3.88	37.10	10.60	2.89	3.12	0.84
6	15	4.3	.25	3.52	26.40	8.81	2.47	2.74	0.79
6	12	3.6	.22	3.38	21.70	7.25	2.47	1.91	0.73
5	13	3.8	.26	3.13	15.70	6.28	2.06	1.98	0.72
5	$9\frac{3}{4}$	2.9	.21	3.00	12.10	4.87	2.06	1.29	0.67
4	10	2.9	.39	2.69	6.84	3.42	1.53	0.89	0.55
4	$7\frac{1}{2}$	2.2	.20	2.50	5.86	2.93	1.63	0.70	0.56
4	6	1.8	.18	2.19	4.59	2.30	1.61	0.38	0.47

TABLE XX.

RADII OF GYRATION FOR TWO ANGLES PLACED BACK TO BACK.

EQUAL LEGS.

Radii of gyration given correspond to directions of the arrowheads.



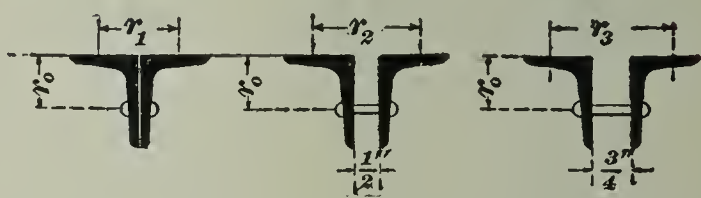
Size. Inches.	Thick-ness. Inches.	Radii of Gyration.			
		r_0.	r_1.	r_2.	r_3.
8×8	$\frac{1}{2}$	2.50	3.32	3.45	3.58
6×6	$\frac{7}{8}$	1.87	2.64	2.83	2.92
6×6	$\frac{7}{16}$	1.87	2.50	2.67	2.76
6×6	$\frac{3}{8}$	1.88	2.49	2.66	2.75
5×5	$\frac{7}{8}$	1.49	2.17	2.35	2.45
5×5	$\frac{3}{4}$	1.55	2.20	2.38	2.48
5×5	$\frac{3}{8}$	1.56	2.09	2.27	2.36
4×4	$\frac{13}{16}$	1.24	1.83	2.03	2.12
4×4	$\frac{3}{8}$	1.23	1.68	1.86	1.95
4×4	$\frac{5}{16}$	1.24	1.67	1.85	1.94
$3\frac{1}{2} \times 3\frac{1}{2}$	$\frac{5}{8}$	1.04	1.51	1.70	1.81
$3\frac{1}{2} \times 3\frac{1}{2}$	$\frac{3}{8}$	1.07	1.47	1.66	1.75
$3\frac{1}{2} \times 3\frac{1}{2}$	$\frac{5}{16}$	1.08	1.46	1.65	1.74
3×3	$\frac{5}{8}$	.94	1.40	1.59	1.69
3×3	$\frac{1}{4}$	.93	1.25	1.43	1.53
$2\frac{3}{4} \times 2\frac{3}{4}$	$\frac{1}{4}$	.85	1.15	1.34	1.44
$2\frac{3}{4} \times 2\frac{3}{4}$	$\frac{1}{2}$	.82	1.19	1.39	1.49
$2\frac{1}{2} \times 2\frac{1}{2}$	$\frac{1}{2}$	.76	1.12	1.31	1.42
$2\frac{1}{2} \times 2\frac{1}{2}$	$\frac{1}{4}$	.77	1.05	1.25	1.34
$2\frac{1}{4} \times 2\frac{1}{4}$	$\frac{1}{2}$	.70	1.05	1.25	1.35
$2\frac{1}{4} \times 2\frac{1}{4}$	$\frac{1}{4}$	.69	.96	1.14	1.24
$2\frac{1}{4} \times 2\frac{1}{4}$	$\frac{3}{16}$	.69	.94	1.12	1.22
2×2	$\frac{1}{2}$	.62	.95	1.15	1.26
2×2	$\frac{3}{16}$	.62	.84	1.03	1.13
$1\frac{1}{2} \times 1\frac{1}{2}$	$\frac{1}{8}$	.47	.63	.77	.92

TABLE XXI.

Radii of Gyration for Two Angles Placed Back to Back Long Leg Vertical.

Unequal Legs.

Radii of gyration given correspond to directions of the arrowheads.



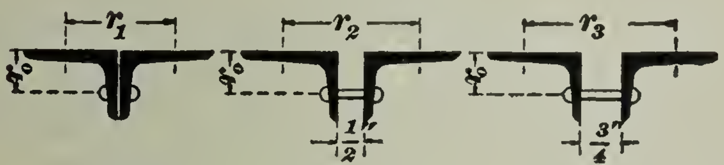
Size. Inches.	Thickness. Inches.	Radii of Gyration.			
		r_0.	r_1.	r_2.	r_3.
6 × 4	7/8	1.95	1.68	1.87	1.97
6 × 4	3/8	1.93	1.50	1.67	1.76
5 × 3½	3/4	1.59	1.44	1.63	1.73
5 × 3½	3/8	1.60	1.34	1.51	1.61
5 × 3	3/4	1.62	1.23	1.42	1.52
5 × 3	5/16	1.61	1.09	1.26	1.36
4½ × 3	3/4	1.43	1.25	1.44	1.55
4½ × 3	5/16	1.45	1.13	1.31	1.40
4 × 3½	3/4	1.24	1.53	1.72	1.83
4 × 3½	5/16	1.26	1.41	1.58	1.69
4 × 3	5/8	1.23	1.20	1.39	1.50
4 × 3	5/16	1.27	1.17	1.35	1.45
3½ × 3	5/8	1.06	1.27	1.46	1.56
3½ × 3	5/16	1.10	1.21	1.39	1.49
3½ × 2½	9/16	1.10	1.04	1.23	1.34
3½ × 2½	1/4	1.12	.96	1.17	1.24
3 × 2½	9/16	.93	1.07	1.27	1.37
3 × 2½	1/4	.95	1.00	1.18	1.28
3 × 2	1/2	.92	.80	1.00	1.10
3 × 2	1/4	.96	.75	.93	1.04
2¼ × 1½	5/16	.70	.60	.79	.91
2¼ × 1½	3/16	.72	.57	.75	.86

TABLE XXII.

Radii of Gyration for Two Angles Placed Back to Back, Short Leg Vertical.

Unequal Legs.

Radii of gyration given correspond to directions of the arrowheads.



Size. Inches.	Thickness. Inches.	Radii of Gyration.			
		r_0.	r_1.	r_2.	r_3.
7 × 3½	7/16	.95	3.37	3.56	3.66
6 × 4	7/8	1.19	2.94	3.13	3.23
6 × 4	3/8	1.17	2.74	2.92	3.02
5 × 3½	3/4	1.01	2.39	2.58	2.68
5 × 3½	3/8	1.02	2.27	2.45	2.55
5 × 3	3/4	.86	2.50	2.69	2.79
5 × 3	5/16	.85	2.33	2.51	2.61
4½ × 3	3/4	.86	2.18	2.38	2.46
4½ × 3	5/16	.87	2.06	2.25	2.33
4 × 3½	3/4	1.05	1.85	2.04	2.14
4 × 3½	5/16	1.07	1.73	1.91	2.00
4 × 3	5/8	.83	1.84	2.03	2.13
4 × 3	5/16	.89	1.79	1.97	2.07
3½ × 3	5/8	.87	1.57	1.76	1.87
3½ × 3	5/16	.90	1.53	1.71	1.81
3½ × 2½	9/16	.72	1.66	1.85	1.95
3½ × 2½	1/4	.74	1.58	1.76	1.86
3 × 2½	9/16	.73	1.40	1.59	1.69
3 × 2½	1/4	.75	1.32	1.49	1.60
3 × 2	1/2	.55	1.42	1.62	1.72
3 × 2	1/4	.57	1.39	1.57	1.68
2½ × 2	1/2	.56	1.16	1.35	1.46
2½ × 2	3/16	.60	1.10	1.28	1.39

COLUMNS.

The columns used in building construction are usually of stone, wood, cast iron, or structural steel. Stone columns are more frequently met with as features of architectural treatment than as supporting members of the structure. When they are used as structural members, they are generally so proportioned that they fail by crushing, and their strength depends on the compressive resistance of the material.

Wooden columns have their principal use in such buildings as large stores, factories, and warehouses, constituting part of a system of slow-burning construction which many consider to be superior to partially fireproof construction embodying cast-iron columns. The argument advanced is that, in case of fire, the wooden columns will become charred upon the outside, and, thus protected, the body of the column will retain its strength and successfully support the loads above; while under similar conditions cast-iron columns will become intensely heated, and, if water is played upon them, will snap and thus prematurely destroy the building. Cast-iron columns are rapidly being superseded by those built up of rolled-steel sections, or, as they are called, structural-steel columns. This is evidently due to the low price of structural steel, and also to the unreliability of cast iron under the action of fire and suddenly-applied loads. Another objection to cast-iron columns is the difficulty of making rigid connection between the columns of the several floors, and also of the floorbeams to the columns. This objection becomes serious when the height of the building increases to 8 or 12 stories; it is on record that, on account of this lack of rigidity in the connections, a certain building in New York was forced by the wind 11 inches out of plumb.

Strength of Columns.—The strength of columns depends upon their length and shape of cross-section. Long columns will fail by bending under less load than will short columns. Of two columns having the same sectional area, the one having the material in the section distributed farthest from the central axis of the column will be stronger than one having the bulk of material located near the center.

If all the material composing the cross-section of a column could be located at a distance from the center equal to the radius of gyration, the column would possess equal strength to resist flexure as though the material was distributed over the cross-section. Hence, in formulas for calculating the strength of columns, both the radius of gyration and the length are to be taken into consideration.

WOODEN COLUMNS.

The formula for determining the strength of wooden columns having flat or square ends was deduced from exhaustive tests of full-size specimens, made at the Watertown Arsenal, Mass., and may be expressed as follows:

$$S = U - \left(\frac{Ul}{100\,d}\right),$$

in which S = ultimate strength of column per square inch of section;

U = ultimate compressive strength of the material per square inch;

l = length of the column in inches;

d = dimension of the least side of the column in inches.

The above formula may be applied to all wooden columns, the length or height of which is *not under 10 times nor over 45 times the dimension of the least side.* In other words, $\frac{l}{d}$ should not be less than 10 nor more than 45. If the length is less than 10 times the least side, the direct compressive strength of the material per square inch, multiplied by the sectional area of the column in square inches, will give the strength of the column. If the length is over 45 times the least side, this formula will not apply; in such cases, provision must be made for bracing the column in all directions, or the load upon it must be greatly reduced. Columns of this dimension, however, seldom occur in building practice.

Having determined S, the breaking load per square inch of section, the safe load per square inch will be obtained by dividing by the required factor of safety, 4, 5, or 6. This

result, multiplied by the sectional area, will give the safe load the column will sustain.

EXAMPLE.—What safe load will a $10'' \times 12''$ Northern yellow-pine column 20 ft. long support, provided a factor of safety of 5 is used?

SOLUTION.—In the formula $S = U - \left(\frac{Ul}{100\,d}\right)$, the value of U for Northern yellow pine is given in Table IX, page 71, as 4,000; l is equal to 20 ft. $\times$ 12 in. = 240 in.; and the least side of the column, or d, is 10 in. By substituting these values in the formula, $S = 4{,}000 - \left(\frac{4{,}000 \times 240}{100 \times 10}\right) = 3{,}040$ lb., the ultimate or breaking strength of the column per square inch of cross-section.

Then, $3{,}040 \div 5$ (factor of safety) = 608 lb., the safe strength of the column to compression per square inch of section.

The sectional area of the column is 12 in. $\times$ 10 in. = 120 sq. in.; hence, the safe load that the column will support is equal to 608×120, or 72,960 lb.

Details of Design.—For slow-burning construction, the Fire Underwriters' Association will not allow the use of square wooden columns less than 8 in. on a side; so, although the actual required size of column to safely sustain the load might be much less than 8 in., it is not advisable in first-class buildings of this construction to use wooden columns less than this size.

Large timber posts—that is, posts not under 8 or 10 in. least dimension—are considered as offering more resistance to fire than cast-iron columns; hence, they are often used, especially in mill construction, in preference to the latter.

Care should be taken in selecting timber for columns or posts to obtain only seasoned wood, without wind or twist, free from defects likely to affect its strength. The ends of the posts should be cut square, so as to take a uniform bearing at the base and cap plates. The timber commonly used for posts is yellow pine, which includes the Northern, Southern, or Georgia pines; white pine, spruce, and Oregon spruce are frequently used, and in some instances, oak.

Details of the usual cast-iron caps and bases which are used with wooden columns are given on page 197.

TABLE XXIII.

APPROXIMATE BREAKING LOADS FOR NORTHERN YELLOW-PINE COLUMNS, IN THOUSANDS OF LB.

Calculated by the formula: $S = U - \left(\frac{U l}{100 d}\right)$. $U = 4{,}000$ lb.

Length. Feet.	6″×6″	7″×7″	8″×8″	9″×9″	10″×10″	11″×11″	12″×12″	13″×13″	14″×14″	16″×16″
8	121	169	225							
9	118	165	220	285						
10	115	162	216	280	352					
11	112	158	214	275	347	425				
12	109	155	210	271	342	420	506			
13	107	152	204	266	336	414	501	592		
14	104	149	202	262	333	410	494	587	685	
15	101	145	198	258	327	406	487	580	680	909
16	98	142	194	253	323	400	483	573	672	901
17	96	138	189	250	318	395	477	568	667	893
18	92	134	186	246	314	388	472	563	660	885
19	89	132	183	242	308	384	466	557	652	878
20	86	128	179	237	304	379	460	550	648	870

The strengths of *spruce*, *hemlock*, and *California redwood* are practically the same as in the table.

For *white pine*, take $\frac{7}{8}$ of the above loads.

For *white oak*, multiply the above loads by $1\frac{1}{8}$.

For *Georgia yellow pine*, multiply by $1\frac{1}{4}$.

By dividing the values in all cases by the required factor of safety, usually 4, 5, or 6, the safe supporting strength of the column will be obtained.

CAST-IRON COLUMNS.

A formula for obtaining the strength of cast-iron columns having flat or square ends is,

$$S = \frac{U}{1 + \left(\frac{l^2}{3{,}600\ R^2}\right)},$$

in which S = breaking strength of column in lb. per sq. in. of section;

l = length of column in inches;

$*R^2$ = square of the least radius of gyration;

$\dagger U$ = ultimate compressive strength of cast iron in lb. per sq. in.

Having calculated the value of S, the safe strength per square inch may be obtained by dividing by the factor of safety. The safe load on the column is then found by multiplying this value by the sectional area of the column in square inches.

EXAMPLE.—Find the proper working load for a 10-in. square cast-iron column, 20 ft. long, using a factor of safety of 6, the thickness of the metal being 1 in.

SOLUTION.—The ultimate compressive strength U of cast iron in lb. per sq. in., according to Table VIII, page 70, is 81,000; the length l equals 20 ft. $\times$ 12 in. = 240 in.; and the formula for determining R^2 for a hollow square column is, according to Table XII, page 83,

$$R^2 = \frac{b^2 + b'^2}{12}.$$

Substituting figures,

$$R^2 = \frac{10^2 + 8^2}{12} = \frac{100 + 64}{12} = 13.6.$$

Upon substituting these values in the formula, there results,

$$S = \frac{81{,}000}{1 + \left(\frac{240 \times 240}{3{,}600 \times 13.6}\right)} = \frac{81{,}000}{2.17} = 37{,}327 \text{ lb. per sq. in.}$$

Using a factor of safety of 6, the safe load per sq. in. of section is $37{,}327 \div 6 = 6{,}221$ lb. Since the net area section is

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* For values of R^2, see page 83. † See page 70.

100 sq. in. — 64 sq. in. = 36 sq. in., the entire load that the column will safely sustain is equal to 6,221 lb. × 36 sq. in. = 223,956 lb.

Design of Cast-Iron Columns.—Since cast-iron columns are usually more or less in a state of internal strain, due to the unequal cooling of the metal in the molds, and also because of the uncertain nature of the casting, a factor of safety of from 6 to 8 should be used in designing them.

Fig. 10 shows a design for a circular cast-iron column. *A* shows the elevation for the cap and brackets supporting steel floorbeams. Special care should be exercised in the design of the bracket *a*, the web being made, as shown at *A*, to extend to the edge of the plate *m*, and with the general outline of its front edge forming an angle of about 60° with *m*. If the web is made as shown by full line at *a* in *B*, and the beam takes a bearing upon the edge of the plate *m*, the tendency will be to fracture the edge of the bracket. It is well to have at least ¼″ fillets in all the corners of the casting, and also to thicken the metal in the column adjacent to the brackets, as shown at *b*.

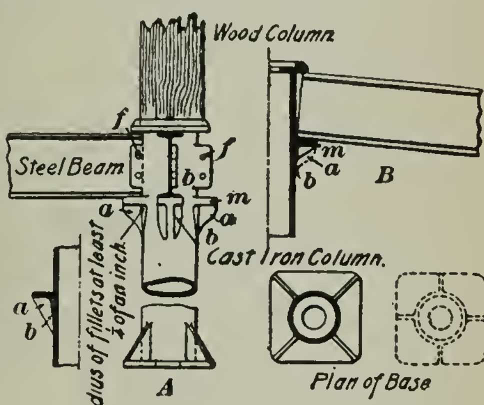

FIG. 10.

The bolt holes *f* should be always drilled, either in the casting or in the steel beams after the latter are in place, because, if the holes are cored in the casting and the holes punched in the beams at the mill, it is likely that the beams will be supported entirely by the shear of the bolts, without bearing upon the bracket at all. The bolts should fit the bolt holes *f* closely, and it is best, if practicable, to drill the holes in both beams and cast-iron flange; this will insure as rigid a connection as is possible with this form of construction.

The strengthening webs of the base should be placed in the most effective position, that is, on the diagonals, as shown in Fig. 10; if placed on the diameters, the corners will have

a tendency to break off, thus reducing the bearing surface of the base.

In designing cast-iron columns a good rule to observe is to have the thickness of the metal in the body of the column not under $\frac{5}{8}$ in. If made less than this, the difficulty of obtaining sound castings is increased, because the metal, in flowing into the mold, is liable to cool before completely filling it, and thus weak spots and dangerous flaws are formed.

Inspection of Cast-Iron Columns.—All building castings, and especially columns, should be carefully inspected before being placed in the building. Air bubbles and blowholes are a common and dangerous source of weakness, and should be searched for by tapping the casting with a hammer. Bubbles or flaws filled in with sand from the mold, or purposely stopped with loam, cause a dullness in the sound. The casting should be free from flaws of any kind, with the exterior surface smooth and clean, and the edges sharp and perfect. An uneven or wavy surface indicates unequal shrinkage. Cast-iron columns should be straight, and cored directly through the center, the metal being as nearly as possible of uniform thickness throughout. It is not unusual to find cast-iron columns, designed to be $\frac{3}{4}$ in. thick throughout, $1\frac{1}{4}$ in. on one side and $\frac{1}{4}$ in. on the other.

The base and cap of a cast-iron column should be turned accurately, being true and perpendicular to the center line.

Fireproofing of Cast-Iron Columns.—Cast-iron columns subjected to the intense heat of a conflagration are liable to destruction when water is played upon them. In consequence, especially when located in important situations and when their failure in case of fire would practically destroy the building, they should be thoroughly fireproofed. There are several means employed to accomplish this. The columns may be incased in a light cast-iron shell, an air space of from 1 to 3 in. being left between the column and the casing; this space is sometimes, but not usually, filled with a incombustible, non-conductive material. Two rough and one finish coats of good hard mortar plaster laid upon an expanded metal casing, surrounding the column, with an air space between, make a good fireproof protection. Terra-cotta tile is also much used.

TABLE XXIV.

Breaking Loads for Square Cast-Iron Columns.

In thousand pounds. $U = 81{,}000$.

Dimen. of Side. In.	Thick-ness. In.	Length of Column in Feet.						
		8 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.	20 ft.
6	$\frac{1}{2}$	594						
6	$\frac{5}{8}$	700	584					
6	$\frac{3}{4}$	820	685	567				
6	$\frac{7}{8}$	929	770	638	535			
7	$\frac{1}{2}$	775	664	573	494	430		
7	$\frac{5}{8}$	840	725	625	532	460	395	
7	$\frac{3}{4}$	1,090	935	810	688	589	505	440
7	$\frac{7}{8}$	1,220	1,060	915	770	660	570	491
7	1	1,368	1,180	1,020	860	780	625	540
8	$\frac{5}{8}$	1,162	1,040	915	805	708	621	540
8	$\frac{3}{4}$	1,380	1,218	1,060	930	815	710	582
8	$\frac{7}{8}$	1,550	1,370	1,220	1,065	930	814	700
8	1	1,730	1,530	1,340	1,169	1,018	882	770
8	$1\frac{1}{8}$	1,900	1,660	1,450	1,248	1,098	950	835
9	$\frac{5}{8}$	1,391	1,262	1,138	1,013	908	800	715
9	$\frac{3}{4}$	1,643	1,473	1,338	1,192	1,060	940	831
9	$\frac{7}{8}$	1,861	1,678	1,510	1,340	1,180	1,060	938
9	1	2,100	1,880	1,690	1,500	1,320	1,176	1,040
9	$1\frac{1}{8}$	2,300	2,070	1,840	1,630	1,450	1,276	1,135
10	$\frac{3}{4}$	1,934	1,784	1,584	1,467	1,328	1,190	1,064
10	$\frac{7}{8}$	2,184	2,000	1,820	1,643	1,485	1,334	1,200
10	1	2,440	2,250	2,040	1,850	1,660	1,490	1,345
10	$1\frac{1}{8}$	2,890	2,650	2,400	2,140	1,930	1,730	1,550
10	$1\frac{1}{4}$	3,040	2,710	2,470	2,225	1,992	1,780	1,600
11	$\frac{7}{8}$	2,510	2,340	2,150	1,950	1,783	1,623	1,484
11	1	2,810	2,650	2,430	2,200	2,020	1,821	1,680
11	$1\frac{1}{8}$	3,100	2,920	2,670	2,440	2,230	2,030	1,840
11	$1\frac{1}{4}$	3,430	3,180	2,930	2,660	2,440	2,200	1,990
12	1	3,150	2,970	2,770	2,570	2,370	2,180	1,980
12	$1\frac{1}{8}$	3,520	3,300	3,007	2,850	2,620	2,420	2,230
12	$1\frac{1}{4}$	3,870	3,620	3,370	3,120	2,870	2,640	2,430
12	$1\frac{3}{8}$	4,170	3,900	3,600	3,350	3,080	2,820	2,570
13	$1\frac{1}{8}$	3,890	3,690	3,460	3,250	3,140	2,780	2,560
13	$1\frac{1}{4}$	4,290	4,070	3,820	3,580	3,340	3,060	2,830
13	$1\frac{3}{8}$	4,650	4,400	4,130	3,940	3,570	3,000	3,040
13	$1\frac{1}{2}$	5,000	4,740	4,420	4,130	3,830	3,520	3,240
14	$1\frac{1}{4}$	4,740	4,530	4,280	4,000	3,760	3,510	3,260
14	$1\frac{3}{8}$	5,060	4,870	4,620	4,340	4,050	3,770	3,520
14	$1\frac{1}{2}$	5,520	5,270	4,980	4,680	4,870	4,060	3,800
14	$1\frac{5}{8}$	5,900	5,610	5,300	5,980	4,650	4,330	4,030

TABLE XXV.

BREAKING LOADS FOR ROUND CAST-IRON COLUMNS.

In thousand pounds. $U = 81{,}000$.

Diam. of Col. In.	Thick-ness. In.	Length of Column in Feet.						
		8 ft.	10 ft.	12 ft.	14 ft.	16 ft.	18 ft.	20 ft.
6	½	418						
6	⅝	505	412					
6	¾	570	465	374				
6	⅞	651	525	423	347			
7	½	560	474	393	332	270		
7	⅝	655	566	476	402	332	287	
7	¾	820	658	544	456	384	324	280
7	⅞	880	732	610	510	425	360	313
7	1	971	810	670	559	470	396	339
8	⅝	850	735	631	542	462	400	352
8	¾	1,000	910	743	640	545	468	405
8	⅞	1,120	960	810	710	620	529	455
8	1	1,260	1,082	930	785	675	578	502
8	1⅛	1,360	1,185	1,005	865	732	625	545
9	⅝	1,040	923	810	710	620	535	480
9	¾	1,220	1,073	950	820	720	628	560
9	⅞	1,360	1,200	1,050	918	805	595	614
9	1	1,550	1,362	1,192	1,039	900	758	682
9	1⅛	1,710	1,500	1,300	1,130	958	851	751
10	¾	1,420	1,280	1,141	1,020	900	798	705
10	⅞	1,640	1,495	1,318	1,170	1,036	910	820
10	1	1,830	1,580	1,460	1,292	1,143	1,010	895
10	1⅛	2,030	1,810	1,470	1,310	1,160	1,110	980
11	¾	1,640	1,510	1,363	1,260	1,120	1,000	895
11	⅞	1,840	1,680	1,540	1,385	1,250	1,113	990
11	1	2,100	1,923	1,740	1,570	1,420	1,258	1,119
11	1⅛	2,300	2,110	1,920	1,720	1,550	1,370	1,217
12	¾	1,869	1,740	1,600	1,440	1,310	1,200	1,080
12	⅞	2,130	1,960	1,800	1,630	1,490	1,360	1,223
12	1	2,380	2,180	2,020	1,840	1,670	1,500	1,360
12	1⅛	2,580	2,350	2,180	1,990	1,800	1,620	1,470
13	¾	2,020	1,900	1,740	1,620	1,480	1,363	1,265
13	⅞	2,400	2,250	2,100	1,920	1,760	1,590	1,465
13	1	2,660	2,480	2,320	2,120	1,940	1,745	1,610
13	1⅛	2,920	2,720	2,540	2,310	2,120	1,900	1,750
14	⅞	2,600	2,450	2,310	2,160	1,970	1,820	1,670
14	1	2,930	2,700	2,580	2,390	2,140	2,090	1,880
14	1⅛	3,250	3,090	2,850	2,670	2,440	2,300	2,070
14	1¼	3,560	3,360	3,140	2,910	2,660	2,440	2,250

STRUCTURAL-STEEL COLUMNS.

The method of securing the ends of a column greatly influences its strength. While wooden and cast-iron columns usually occur in building construction with flat or square ends, structural-steel columns are often used, having either hinged, flat or square, and fixed ends. Where the ends are securely fixed, so that the column is likely to fail in the shaft, before the end connections are ruptured, greater strength is developed than with columns having hinged or pinned ends. Columns having flat or square ends are somewhat stronger than hinged-end columns, but not so strong as those having their ends firmly secured.

The strength of structural-steel columns may be determined by the following formulas:

For Fixed Ends.

$$S = \frac{U}{1 + \left(\frac{l^2}{36,000\,R^2}\right)},$$

For Square Ends.

$$S = \frac{U}{1 + \left(\frac{l^2}{24,000\,R^2}\right)},$$

For Pin Ends.

$$S = \frac{U}{1 + \left(\frac{l^2}{18,000\,R^2}\right)},$$

in which S = ultimate strength of column in pounds per square inch;
U = ultimate compressive strength of the material in pounds per square inch;
l = length of column in inches;
*R = least radius of gyration.

The value of U for structural steel is usually taken at from 52,000 to 54,000 lb. for soft steel, and as high as 60,000 for medium steel.

Having determined S, the safe load per square inch is found by dividing S by the factor of safety. This quotient, multiplied by the area of the section, will give the safe load the column will sustain.

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* See page 81.

EXAMPLE.—What safe load will a square-end structural-steel column, 20 ft. long, having the section shown in Fig. 11, support, taking the ultimate compressive strength at 52,000 lb. per sq. in., and using a factor of safety of 5?

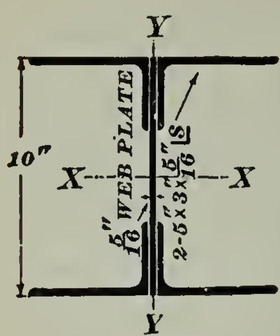


FIG. 11.

SOLUTION.—First calculate the radius of gyration about both the axes $X X$ and $Y Y$, by the method given on page 81. This will determine the least radius of gyration, which in this case is around the axes $Y Y$, and is approximately 2.13 in. The value of R^2 will then be $2.13 \times 2.13 = 4.53$. The value of l, the length of the column in inches, is 20 (ft.) $\times$ 12 (in.) = 240 in.; and $l^2 = 240 \times 240 = 57,600$. Substituting the above values in the formula,

$$S = \frac{U}{1 + \left(\frac{l^2}{24,000\,R^2}\right)},\ S = \frac{52,000}{1 + \left(\frac{57,600}{24,000 \times 4.53}\right)} = 34,000,$$

which is the ultimate strength of the column in pounds per square inch of section.

The total sectional area is as follows:

* Area of 4 — 5″ × 3″ × $\frac{5}{16}$″ angles	= 2.40 × 4	=	9.60 sq. in.
† Area of $\frac{5}{16}$″ × 10″ web-plate	= 10 × .3125	=	3.125 sq. in.
	Total area of section	=	12.725 sq. in.

Then 34,000 (ultimate strength of the column in pounds per square inch of section) × 12.72 (sq. in.) = 432,480 lb. The factor of safety required being 5, the safe load that the column will support is 432,480 ÷ 5 = 86,496 lb.

The formulas above given being somewhat awkward to use, more convenient ones have been deduced, and while they give somewhat different values for S than those obtained by the previously stated formulas, the differences are on the side of safety. These formulas may be applied to columns whose lengths are between 50 and 150 least radii of gyration;

* See table, page 86.

† For table of decimal equivalents, see page 53.

that is, if the radius of gyration of a column is 2 in., these formulas will apply to columns whose lengths are between 100 and 300 in.

	Medium Steel.	*Soft Steel.*
Fixed ends,	$S = 60{,}000 - 210\frac{l}{R}$	$S = 54{,}000 - 185\frac{l}{R}$
Square ends,	$S = 60{,}000 - 230\frac{l}{R}$	$S = 54{,}000 - 200\frac{l}{R}$
Pin ends,	$S = 60{,}000 - 260\frac{l}{R}$	$S = 54{,}000 - 225\frac{l}{R}$

In these formulas,

S = ultimate or breaking strength of the column in pounds per square inch of sectional area;

l = length of the column in inches;

R = least radius of gyration in inches.

EXAMPLE.—What is the ultimate strength in pounds, per square inch of section, for a fixed-end column 22 ft. long, the least radius of gyration for the section being 2.5 in. and the material being medium steel?

SOLUTION.—The formula $S = 60{,}000 - 210\frac{l}{R}$, by substituting the values for l and R, becomes

$$S = 60{,}000 - 210\frac{264}{2.5} = 37{,}824 \text{ lb.},$$

the ultimate strength per square inch of column section.

Structural columns are usually considered as having square ends, and a factor of safety of 4 is generally allowed. The following formulas will give the allowable stress in pounds per square inch which such columns will sustain:

Medium Steel.	*Soft Steel.*
$S = 15{,}000 - 57\frac{l}{R}$	$S = 13{,}500 - 50\frac{l}{R}$

The formula for medium-steel columns is for lengths over 50 times the least radius of gyration; that for soft-steel columns is for lengths over 30 times the least radius of gyration. For columns of dimensions less than these figures, a safe load of 12,000 lb. per sq. in. of section can safely be assumed.

No column should be used whose length is greater than 150 least radii of gyration, or whose length exceeds 45 times the least dimension of the column.

Design of Structural-Steel Columns.—Structural-steel columns should be so designed that, where several lengths are connected end to end, the splice may be made in a rigid and secure manner; they should also be so constructed as to facilitate connecting floorbeams or girders on all sides. All beam connections to the column should be carefully designed and provided with sufficient rivets, to avoid failure of the connections by shearing of the rivets. Rivets in columns should be so spaced as not to exceed 3 in. center to center, at the ends of the column, for a distance equal to twice the width of the column. The distance between rivets from center to center, in a direction parallel with the line of strain, should not exceed 16 times the least thickness of metal of the parts joined; and the distance from center to center between the rivets at right angles to the line of strain should not exceed 32 times the least thickness of metal. Further considerations in regard to rivets and rivet spacing are given on pages 128 to 133.

BEAMS AND GIRDERS.

A body resting upon supports and liable to transverse stress is called a *beam*. Beams are designated by the number and location of the supports, and may be either simple, cantilever, fixed, or continuous. A *simple* beam is one that is supported at each end, the distance between its supports being the *span*. A *cantilever* is a beam that has one or both ends overhanging the support; a beam having one end firmly fixed and the other end free is a cantilever. A *fixed* beam is one that has both ends firmly secured. A *continuous* beam is one which rests upon more than two supports.

MOMENTS.

The *moment* of a force around a fixed point is equal to the force multiplied by its lever arm, which is the perpendicular distance from the line of action of the force to the point; this product is called *foot-pounds* or *inch-pounds*, according to the unit used. Thus in (a), Fig. 12, the moment about c = 10 lb.

× 10 ft. = 100 ft.-lb. In (b) the moment about c is 10 lb. × 8 ft. = 80 ft.-lb. Likewise in (c) the moment around c is 20 lb. × 24 in. = 480 in.-lb. In (d), the beam is supported at c; the force a has a moment about c of 30 lb. × 8 ft. = 240 ft.-lb., acting in a direction contrary to the motion of clock hands. The force b has a moment about c of 20 lb. × 10 ft. = 200 ft.-lb., acting in the direction of motion of clock hands. It is evident that the beam will turn around c in the direction of the greater moment, with a moment of 240 ft.-lb. — 200 ft.-lb. = 40 ft.-lb.; the beam is, therefore, not in *equilibrium.* If a force of 4 lb. be added to b, creating a moment of 4 lb. × 10 ft. = 40 ft.-lb., to counterbalance the moment of 40 ft.-lb. tending to rotate the beam, the latter will then be in equilibrium. Hence, moments tending to produce rotation in the same direction are alike, and should be added; those acting in opposite directions are unlike, and the smaller should be deducted from the greater. The total moment of a system of forces about a point is the algebraic sum of the moments of all the forces around that point. *If a body is in equilibrium, the algebraic sum of the moments of the forces acting upon that body is zero about any point in that body.*

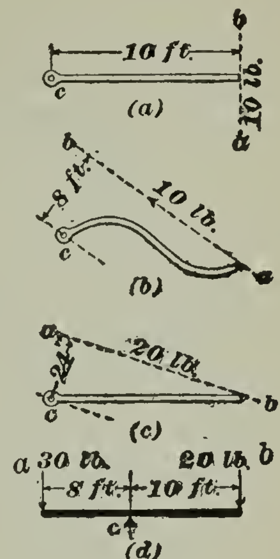


FIG. 12.

THEORY OF BEAMS.

If a beam is loaded as at $W\ W\ W$, Fig. 13, the weights produce reactions at the supports. These forces, or reactions, R_1, and R_2, oppose the action of the weights and their combined action must equal the total weight. The weights and reactions, constituting the external forces, tend to produce bending in the beam, and are resisted by the internal forces, consisting of the strength of the fibers composing the beam. In a simple

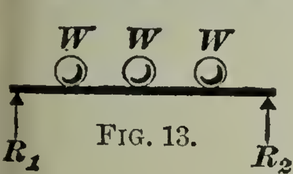


FIG. 13.

beam, the effect of loading is to shorten the upper fibers, and to lengthen the lower ones. Somewhere between the top and bottom of the cross-section are located fibers which are neither shortened nor lengthened; this position is called the *neutral axis* (see page 75). In steel and like material of homogeneous nature, the neutral axis passes through the center of gravity of the section.

At any point in the length of a beam, the tendency to produce bending is equal to the algebraic sum of the moments of the external forces at that point; this moment is called the *bending moment.* A beam resists bending at any point by the resistance of its particles to extension or compression, the sum of the moments of which about the neutral axis of the cross-section is called the *moment of resistance*, or *resisting moment.* For a beam to be sufficiently strong to sustain the load, the *moment of resistance must equal the bending moment.* If the moment of resistance is expressed in inch-pounds, the bending moment must likewise be reduced to inch-pounds.

Reactions.—The reactions or supporting forces of any beam or structure must equal the loads upon it. If the load upon a simple beam is uniformly distributed, applied at the center of the span, or symmetrically placed and of equal amount upon each side of the center, the reactions R_1 and R_2 will each be equal to one-half the load. When the loads are not symmetrically placed, the reactions are found by the principle of moments in the following manner:

Fig. 14 represents a simple beam supporting loads W_1, W_2, and W_3; l is the span or distance between the reactions R_1 and R_2; a, b, and c are the distances from the reaction R_1 to the loads W_1, W_2, W_3, respectively. Then the right-hand reaction, $R_2 =$

$$\frac{(W_1 \times a) + (W_2 \times b) + (W_3 \times c)}{l}.$$

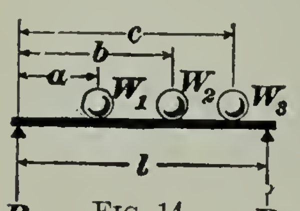


FIG. 14.

This formula expressed in a general rule is: *To find the reaction at either support, multiply each load by its distance from the other support, and divide the sum of these products by the distance between supports.*

Since the sum of the reactions must equal the sum of the loads, if one reaction is found, the other can be obtained by subtracting the known one from the sum of the loads.

EXAMPLE.—What are the reactions at R_1 and R_2, Fig. 15?

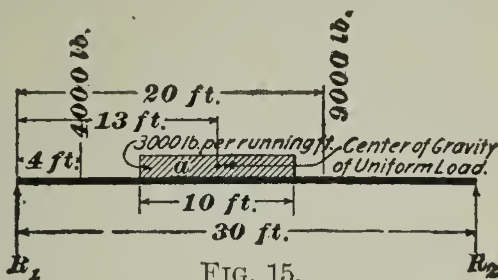


FIG. 15.

SOLUTION.—The lever arm of a uniformly distributed load is always the distance from the center of moments to the center of gravity of the load. The total uniform load a is $3{,}000 \times 10 = 30{,}000$ lb., and the distance of its center of gravity from R_1 is 13 ft. The moments of the loads about R_1 are as follows:

$$
\begin{aligned}
4{,}000 \text{ lb.} \times 4 \text{ ft.} &= 16{,}000 \text{ ft.-lb.} \\
30{,}000 \text{ lb.} \times 13 \text{ ft.} &= 390{,}000 \text{ ft.-lb.} \\
9{,}000 \text{ lb.} \times 20 \text{ ft.} &= 180{,}000 \text{ ft.-lb.} \\
\text{Total} &= 586{,}000 \text{ ft.-lb.}
\end{aligned}
$$

The distance from R_1 to R_2 is 30 ft.; hence, $586{,}000 \div 30 = 19{,}533\frac{1}{3}$ lb., the reaction at R_2. As the sum of the loads is 43,000 lb., the reaction at R_1 is $43{,}000 - 19{,}533\frac{1}{3} = 23{,}466\frac{2}{3}$ lb.

Shear.—The loads and reactions, besides causing bending or flexure, create shearing stresses in the beam by their opposing tendency; that is, as the reactions act upwards and the loads downwards, the effect is to shear the fibers of the beam vertically. *At any section of a beam, the shear is equal to either reaction minus the sum of the loads between that reaction and the section considered.* The maximum shear is always equal to the greatest reaction. For a simple beam with a uniformly distributed load, the maximum shear is at the supports, and is equal to one-half the load, or to the reaction; the shear changes at every point of the loaded length, the minimum shear being zero at the center of the span. The maximum shear in a simple beam having a single load concentrated at the center is equal to one-half the load, and is uniform throughout the beam. Where a beam supports

several concentrated loads, changes in the amount of shear occur only at the points where the loads are applied.

For example, in the beam loaded as shown in Fig. 16, the shear on the line ab is equal to the reaction R_1 of 40 lb. minus the load n of 10 lb., or 30 lb. The shear between o and p, on the line cd, is equal to the reaction R_1 of 40 lb. minus the sum of the loads n, m, and o, or zero. Working from the same reaction R_1, the shear on the beam between p and q is equal to $R_1 - (n + m + o + p)$, or 40 lb. − 55 lb. = −15 lb. Thus, all the beam to the left of o is in what may be called *positive* shear, while to the right of p the shear is in the opposite direction, and may be called *negative* shear. It is evident that there is a section in the beam—for instance, cd—where the shear changes from positive (+) to negative (−); that is, it *passes through zero*, or *changes sign*.

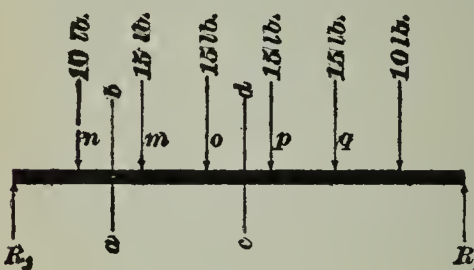


FIG. 16.

EXAMPLE.—(*a*) What is the maximum shear on the beam shown in Fig. 15? (*b*) What is the shear 11 ft. from the right support? (*c*) Where does the shear change sign?

SOLUTION.—(*a*) Taking the center of moments at R_2, the reaction at R_1 is as follows:

$$
\begin{aligned}
9{,}000 \text{ lb.} \times 10 \text{ ft.} &= 90{,}000 \text{ ft.-lb.}\\
3{,}000 \text{ lb.} \times 10 \text{ ft.} \times 17 \text{ ft.} &= 510{,}000 \text{ ft.-lb.}\\
4{,}000 \text{ lb.} \times 26 \text{ ft.} &= 104{,}000 \text{ ft.-lb.}\\
\text{Total} &= 704{,}000 \text{ ft.-lb.}
\end{aligned}
$$

Then, $704{,}000 \div 30 = 23{,}466\frac{2}{3}$ lb., the reaction R_1. The total load being 43,000 lb., the reaction R_2 is $43{,}000 - 23{,}466\frac{2}{3} = 19{,}533\frac{1}{3}$ lb.; hence the maximum shear is R_1. (*b*) The reaction R_2 being $19{,}533\frac{1}{3}$ lb., and there being but a load of 9,000 lb. between it and a section 11 ft. distant, the shear at the latter point is $19{,}533\frac{1}{3} - 9{,}000 = 10{,}533\frac{1}{3}$ lb. (*c*) Working from R_1, the first load is 4,000 lb., and the shear at this point is $23{,}466\frac{2}{3}$ −

4,000 = 19,466⅔ lb. Then enough of the uniform load must be taken to equal this amount. It is clear that the shear becomes negative somewhere in the uniform load, since the latter is 30,000 lb., or more than 19,466⅔ lb. Dividing 19,466⅔ by 3,000, the load per foot, the result is 6.48 ft., the distance from left end of uniform load to point where the shear changes sign; hence the distance from R_1 is 4 + 4 + 6.48 = 14.48 ft.

Bending Moment.—The algebraic sum of the moments of the external forces about any point in a beam is the bending moment at that point; that is, the bending moment at any point is the moment *about that point* of either reaction minus the sum of the moments of the intermediate loads about the same point. For example, the bending moments at several points on the beam shown in Fig. 17 are as follows: At $W_1 = R_1\,a$; at $W_2 = R_1\,(a+b) - W_1\,b$; at $W_3 = R_1\,(a+b+c) - [W_2\,c + W_1\,(b+c)]$, or $R_2\,d$, etc.

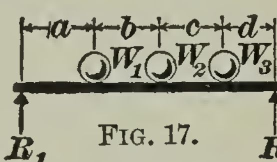


FIG. 17.

The bending moment varies, depending on the shear, and attains a maximum value at the point *where the shear changes sign.* If the loads are concentrated at several points, the maximum bending moment will be under the load at which the sum of all the loads between one support up to and including the load in question first becomes equal to, or greater than, the reaction at the support. Hence, to find the maximum bending moment in any simple beam:

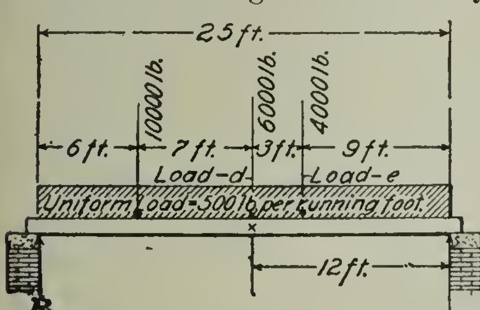


FIG. 18.

Rule.—*Compute the reactions and determine the point where the shear changes sign. Calculate the moment about this point of either reaction, and of each load between the reaction and the point, and subtract the sum of the latter moments from the former.*

EXAMPLE.—What is the maximum bending moment in inch-pounds of the beam loaded as shown in Fig. 18?

SOLUTION.—Taking moments about R_1 and remembering

that a uniform load has the same moment as an equal load concentrated at the center of gravity of the uniform load, the total moment is found to be 358,250 ft.-lb. The span being 25 ft., the reaction R_2 is 358,250 ÷ 25 = 14,330 lb. As the sum of the loads is 32,500 lb., the reaction R_1 is 32,500 − 14,330 = 18,170 lb. This is the greatest reaction and greatest shear.

Beginning at R_1 and adding the loads in succession, it is found that the load of 10,000 lb. plus the uniform load between the reaction and the load d is 10,000 + (500 × 13) = 16,500 lb., which is less than the left reaction, or R_1; when, however, the load d is added, the sum of the loads is greater than the reaction; hence, the shear changes sign under the load d, and the greatest bending moment is also at that point. Taking moments about the point under the load d, the moment of R_1 is 18,170 × 13 = 236,210 ft.-lb. The moments of the loads between d and R_1 are:

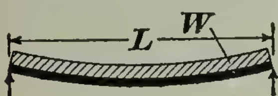
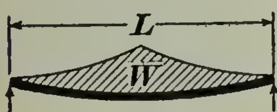
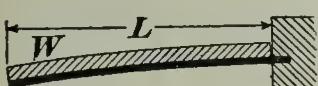
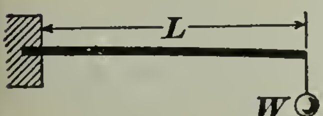
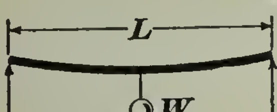
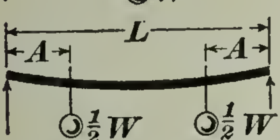
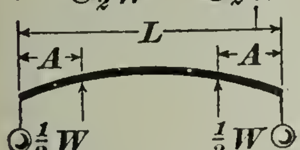
6,500 lb. × 6½ ft.	=	42,250 ft.-lb.
10,000 lb. × 7 ft.	=	70,000 ft.-lb.
Total	=	112,250 ft.-lb.

Then, 236,210 ft.-lb. − 112,250 ft.-lb. = 123,960 ft.-lb., the maximum bending moment. The bending moment in inch-pounds is 123,960 ft.-lb. × 12 = 1,487,520 in.-lb.

If W = the load and L = the span, the maximum bending moment in a simple beam uniformly loaded is $\frac{W}{2} \times \frac{L}{2} - \frac{W}{2} \times \frac{L}{4} = \frac{WL}{8}$. $\left(\frac{L}{4}\right.$ is the distance from the center of beam to center of gravity of each half of the uniform load.) The maximum bending moment in a beam with a load concentrated at the center is $\frac{WL}{4}$. Thus, *a beam uniformly loaded will carry safely twice as much as if the load were concentrated at the center.*

While, by the preceding principles, the bending moment in any beam supported at one or two supports may be determined, it is more convenient to use concise formulas. The following table gives formulas for the maximum bending moment, maximum safe loads, and greatest deflections (or sag), for beams loaded and supported in different ways;

TABLE XXVI.

Method of Loading. Length in Feet. | Load in Pounds.	Maximum Bending Moment. *M.* Ft.-Lb.	In.-Lb.	Maximum Load. *W.* Lb.	Deflection. *D.* In.
	$\frac{WL}{8}$	$\frac{3WL}{2}$	$\frac{2QS}{3L}$	$\frac{5Wl^3}{384EI}$
	$\frac{WL}{6}$	$2WL$	$\frac{QS}{2L}$	$\frac{Wl^3}{60EI}$
	$\frac{WL}{2}$	$6WL$	$\frac{QS}{6L}$	$\frac{Wl^3}{8EI}$
	WL	$12WL$	$\frac{QS}{12L}$	$\frac{Wl^3}{3EI}$
	$\frac{WL}{4}$	$3WL$	$\frac{QS}{3L}$	$\frac{Wl^3}{48EI}$
	$\frac{WA}{2}$	$6WA$	$\frac{QS}{6A}$	$\frac{Wa}{48EI}\times(3l^2-4a^2)$
	$\frac{WA}{2}$	$6WA$	$\frac{QS}{6A}$	Between Supports. $\frac{Wa}{16EI}\times(l-2a)^2$

L = length in feet; l = length in inches; W = total load in pounds; E = modulus of elasticity; I = moment of inertia; Q = section modulus; S = safe stress on the extreme fibers of the beam section (= modulus of rupture ÷ factor of safety). In figuring deflections, all lengths must be expressed in *inches;* and small letters l, a, and b are used as reminders.

Resisting Moment.—The moment of resistance of a beam is the sum of the moments about the neutral axis of all the stresses in the fibers composing the section. The *safe resisting moment of any beam section is equal to the product of the safe fiber stress and the moment of inertia divided by the distance from the neutral axis to the extreme fibers.* If I is the moment of inertia, c the distance in inches from the neutral axis to the extreme fibers, and S the safe fiber stress in pounds per square inch, the resisting moment $M_1 = \frac{IS}{c}$; but since $\frac{I}{c} = Q$, the section modulus (see page 82), $M_1 = QS$; that is, *the safe resisting moment is equal to the safe fiber stress multiplied by the section modulus.* To obtain the safe unit fiber stress, the modulus of rupture of the material (see Tables VIII, IX, X) is divided by the required factor of safety.

EXAMPLE.—What is the safe resisting moment of a Northern yellow-pine beam 10 in. wide $\times$ 12 in. deep, using a factor of safety of 4?

SOLUTION.—In the formula $M_1 = QS$, the section modulus Q for a rectangular section (by Table XII) is $\frac{b\,d^2}{6}$, or, for the given section, $Q = \frac{10 \times 12 \times 12}{6} = 240$. From Table IX, the modulus of rupture for Northern yellow pine is 6,000 lb.; the desired factor of safety being 4, the safe unit fiber stress S is $6{,}000 \div 4 = 1{,}500$ lb. Then $QS = 1{,}500 \times 240 = 360{,}000$, the safe resisting moment, or M_1, of the beam section in inch-pounds.

A beam will safely support a given load when the safe resisting moment M_1, in inch-pounds, is equal to, or greater than, the bending moment M *also in inch-pounds.* Economical design requires that the safe resisting moment be but little, if any, in excess of the bending moment, having regard, also, to the nearest commercial, or stock, sizes.

Deflection.—Stiffness in beams is as important as strength. Lack of stiffness causes vibrations, springy floors, deflection, or sagging, producing plaster cracks in ceilings. To prevent excessive deflection, shallow beams must be avoided. The deflection of beams carrying plastered ceilings should not exceed $\frac{1}{360}$ of the span. Usually this limit is not exceeded

when the depth of wooden beams is at least $\frac{1}{16}$ the span. In dwellings, the full floor load being seldom realized, and as bridging is used between joists, their depth may, with safety, be 14 in. for a span as great as 22 ft. The depth of rolled-steel beams should not be less than $\frac{1}{24}$ the span, and that of plate girders not less than $\frac{1}{15}$. If doubt exists as to the stiffness of a beam, its deflection should be calculated by formulas from Table XXVI, and if found excessive, the load should be diminished, or the size of beam increased.

EXAMPLE.—A $6'' \times 10''$ white-oak beam, uniformly loaded with 5,000 lb., has a span of 16 ft. 8 in. What is the deflection?

SOLUTION.—From Table XXVI, the deflection $= \frac{5\,W l^3}{384\,E\,I}$; from Table IX, $E = 1{,}100{,}000$; $I = \frac{b\,d^3}{12} = \frac{6 \times 1{,}000}{12} = 500.$

Hence, deflection $= \frac{5 \times 5{,}000 \times 8{,}000{,}000}{384 \times 1{,}100{,}000 \times 500} = .94$ in.

CALCULATION OF BEAMS.

Wooden Beams.—These are principally used to support a uniformly distributed load, consequently a convenient formula for determining directly the safe strength of rectangular beams uniformly loaded is useful, and may be deduced from the foregoing principles as follows: The bending moment M in foot-pounds is $\frac{W\,L}{8}$, or in inch-pounds, $\frac{12\,W\,L}{8}$. Placing this equal to the resisting moment, M_1, or $Q\,S$, there results $\frac{12\,W\,L}{8} = Q\,S$, or $12\,W\,L = 8\,Q\,S$; whence $W = \frac{8\,Q\,S}{12\,L} = \frac{2}{3}\frac{Q\,S}{L}$. For a rectangular beam, the section modulus $Q = \frac{b\,d^2}{6}$, and the above formula may be written $W = \frac{2}{3}\frac{S}{L}\frac{b\,d^2}{6} = \frac{S\,b\,d^2}{9\,L}$; b and d are in *inches* and L in *feet*. This formula expressed in words is as follows:

Rule.—*The safe uniformly distributed load in pounds for a rectangular beam is equal to the safe unit fiber stress multiplied by the breadth in inches and by the square of the depth in inches, and the product divided by nine times the span in feet.*

TABLE XXVII.

SAFE UNIFORMLY DISTRIBUTED LOADS FOR RECTANGULAR WOODEN BEAMS, 1 INCH THICK.

Span in Feet.	Depth of Beam.							
	6″	7″	8″	9″	10″	12″	14″	16″
5	800	1,090	1,420	1,800	2,220	3,200	4,380	5,690
6	665	910	1,190	1,500	1,850	2,670	3,650	4,740
7	570	780	1,020	1,290	1,590	2,290	3,130	4,060
8	500	680	890	1,130	1,390	2,000	2,740	3,560
9	445	610	790	1,000	1,230	1,780	2,430	3,160
10	400	540	710	900	1,110	1,600	2,190	2,840
11	365	495	650	820	1,010	1,450	1,990	2,590
12	335	450	590	750	930	1,330	1,820	2,370
13	310	420	550	690	860	1,230	1,690	2,200
14	285	390	510	640	800	1,150	1,570	2,040
15	265	360	480	600	740	1,070	1,460	1,900
16	250	340	450	560	700	1,000	1,370	1,780
17	235	320	420	530	650	940	1,290	1,680
18	220	300	400	500	620	890	1,220	1,590
19	210	290	380	480	590	840	1,150	1,500
20	200	272	360	450	560	800	1,090	1,420
21	190	260	340	430	530	760	1,040	1,360
22	180	248	325	410	510	730	1,000	1,300
23	175	237	310	390	480	700	950	1,240
24	165	228	297	380	460	670	910	1,190
25	160	218	285	360	450	640	880	1,140
26	155	210	275	350	430	620	840	1,100
27	149	202	265	330	410	590	810	1,060
28	143	195	255	315	400	570	780	1,020
29	138	188	246	307	380	550	750	980
30	134	182	237	297	370	530	730	950

Safe load for any thickness = safe load for 1 in. × thickness in inches.

Thickness for any load = load ÷ safe load for 1 in.

The values given are safe loads for spruce or white-pine beams, with a factor of safety of 4. For oak, or Northern yellow pine, multiply tabular values by $1\frac{1}{2}$, and for Georgia yellow pine, multiply tabular values by $1\frac{3}{4}$.

Table XXVII is calculated for a maximum fiber stress of 1,000 lb. per sq. in., but may be used with any fiber stress by dividing that stress by 1,000 and multiplying by the tabular value; thus, for a stress of 800 lb., the safe load is .8 the tabular value.

Loads given below the heavy zigzag line produce deflections likely to crack plastered ceilings.

EXAMPLE.—What uniformly distributed load will a hemlock joist 3 in. wide × 14 in. deep safely support, the span being 20 ft., and the factor of safety, 5?

SOLUTION.—In the formula $W = \frac{S\,b\,d^2}{9\,L}$, $S = 3{,}500$ lb., the modulus of rupture of hemlock (see Table IX), ÷ 5, the factor of safety, = 700 lb. per sq. in.; $b = 3$ in.; $d^2 = 14$ in. × 14 in. = 196; and $L = 20$ ft. Then the safe uniformly distributed load $W = \frac{700 \times 3 \times 196}{9 \times 20} = 2{,}287$ lb.

Otherwise, from Table XXVII, the safe load with a fiber stress of 1,000 lb. per sq. in. for this beam = the load for 1 in. width × the width, or $1{,}090 \times 3 = 3{,}270$ lb.; but for a safe stress of 700 lb. per sq. in., the safe load is $\frac{700}{1{,}000} = .7$ of 3,270 lb. = 2,289 lb.

The following example shows how to calculate the size of a rectangular beam necessary to support a given load:

EXAMPLE.—What size Georgia yellow-pine joist would be required to support two concentrated loads placed as shown in Fig. 19, using a factor of safety of 4?

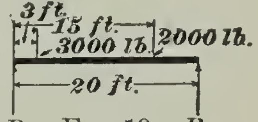


FIG. 19.

SOLUTION.—The reaction $R_2 = \frac{(3{,}000 \times 3) + (2{,}000 \times 15)}{20} = 1{,}950$ lb., and $R_1 = (3{,}000 + 2{,}000) - 1{,}950 = 3{,}050$ lb. The greatest bending moment M is found, by trial, to be under the 2,000 lb. load, and is equal to 1,950 lb. × 5 ft. = 9,750 ft.-lb., or 117,000 in.-lb. Such a section must be obtained that will have a resisting moment equal to this bending moment of

117,000 in.-lb. The modulus of rupture of yellow pine, 7,000 lb., divided by the factor of safety 4, gives a unit fiber stress of 1,750 lb. Then as the resisting moment of any beam section, $M_1 = Q\,S$, by transposition, $Q = \frac{M_1}{S}$, or $\frac{117{,}000}{1{,}750} = 67$, the required section modulus.

By Table XII, for any rectangular section, $Q = \frac{b\,d^2}{6}$. By trial, the value of Q for a $3'' \times 10''$ beam is 50; as this is evidently too small, try a $3'' \times 12''$ beam; for this Q is 72, which is ample, and this beam is selected, being the nearest stock size.

Rolled-Steel Beams.—In calculating the size of steel beam sections, the greatest bending moment is first calculated; then the section modulus required is equal to the bending moment in *inch-pounds* divided by the safe unit fiber stress, obtained by dividing the modulus of rupture of the material by the factor of safety. This may be expressed in formula as $Q = \frac{M}{S}$, in which, as before, Q = section modulus; M = bending moment in inch-pounds, and S = safe or allowable unit fiber stress in pounds per square inch. Having found the section modulus, the proper size channel or **I** beam may be selected from Tables XIII and XIX, the one being chosen which has a section modulus (see column headed Q) nearest to that required, the deepest beam having the required section modulus and lightest weight being preferred.

In selecting rolled structural-steel beams *the depth of the beam in inches should never be less than one-half the span in feet*, in order to avoid excessive deflection, which causes cracks in plastered ceilings. For instance, if the span is 20 ft., a beam should be not less than 10 in. deep.

Example.—The brick-and-concrete floor of an office building weighs 110 lb. per sq. ft., and is designed for a live load of 40 lb. per sq. ft. The span of the beams is 20 ft., and they are spaced 5 ft. on centers. Using a factor of safety of 4, what size steel **I** beams are required?

Solution.—Total load is 110 lb. + 40 lb. = 150 lb. per sq. ft.; floor surface supported upon one beam is 20 ft. $\times$ 5 ft. = 100 sq. ft.; total load on one beam is 100 sq. ft. $\times$ 150 lb. = 15,000 lb.,

$= W$. The load being uniformly distributed, the bending moment, M, by Table XXVI, is $\frac{WL}{8} = \frac{15{,}000 \times 20}{8} = 37{,}500$ ft.-lb. or 450,000 in.-lb. The modulus of rupture for structural steel being about 60,000 lb. (see Table VIII), and the required factor of safety, 4, the allowable unit fiber stress is $60{,}000 \div 4 = 15{,}000$ lb. The section modulus, $Q = \frac{M}{S}$; substituting the values of M and S, $Q = \frac{450{,}000}{15{,}000} = 30$. From Table XIX, page 90, it is found that a 10″ beam weighing 33 lb. per ft. has a section modulus of 32.3, and would meet the requirements. It is, however, seen that for a 12″ beam, weighing $31\frac{1}{2}$ lb. per ft., $Q = 36.7$; and on account of its greater strength and less weight, this beam would be by far the most economical.

Stone Beams.—The strength of lintels, flagstones, etc. may be calculated as rectangular beams, except that it is usual to use a factor of safety at least of 10. It is, however, more convenient to use the formula,

$$W = \frac{b\,d^2}{l} \times c,$$

in which W = safe uniformly distributed load in tons of 2,000 pounds;
b = breadth of beam in inches;
d = depth of beam in inches;
l = span of beam in inches;
c = coefficient taken from the following table:

Kind of Stone.	Coefficient.
Bluestone	.18
Granite	.12
Limestone	.10
Sandstone	.08
Slate	.36

EXAMPLE.—A limestone lintel 20 in. wide $\times$ 14 in. thick spans a 42″ opening. What is the safe distributed load?

SOLUTION.—Substituting values in the formula, $\frac{b\,d^2}{l} \times c$,

$$W = \frac{20 \times 14 \times 14}{42} \times .10 = 9.33 \text{ tons} = 18{,}660 \text{ lb.}$$

If the load is concentrated at the center of the span, the safe load will be one-half the safe uniform load.

DESIGN OF RIVETED GIRDERS.

For heavy loads and long spans, *plate girders* are substituted for rolled beams. A plate girder consists of a web-plate,

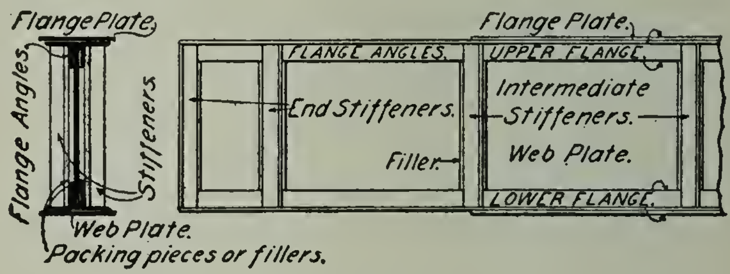


FIG. 20.

with stiffeners, if required, and of the upper and lower flanges, as shown in Fig. 20.

Loads upon a plate girder develop shearing stresses, resisted by the web-plate, and horizontal compressive and tensile stresses, resisted by the upper and lower flanges. The usual cross-sections of plate girders are shown in Fig. 21. The single-webbed girders (*a*) are the most economical in material, and the most accessible for painting and inspection. The box girders (*b*), however, may be used to advantage where a wide top flange is required for lateral stiffness.

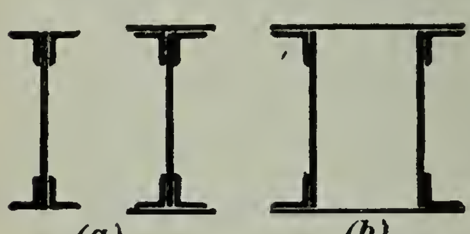


FIG. 21.

Proportioning Web.—The width of the web-plate governs the depth of the girder, which, to avoid excessive deflection,

should not be less than $\frac{1}{15}$ the clear span, although some authorities permit $\frac{1}{20}$. If made more shallow, the sectional area of the flanges should be increased, so as to reduce the stress on them, and the deflection in proportion.

The thickness of web-plates depends upon the shear, which is greatest at the supports. This thickness must be such that the internal resistance to shear—found by multiplying the area of cross-section of web by the safe unit shearing stress—shall be equal to the maximum shear on the girder; that is, if A be the area of cross-section, in square inches; s, the safe unit shearing stress; and S, the maximum shear, then $A\,s = S$; but as A is equal to the thickness (t) in inches multiplied by the net depth (d'), in inches, $t\,d'\,s = S$, or $t = \frac{S}{d'\,s}$. Hence, *the necessary thickness in inches of web is equal to the maximum shear divided by the product of the net depth of the girder in inches times the safe unit shear.* The net depth is the width of the web minus the sum of diameters of all rivet holes in a vertical line at the end stiffeners. The safe unit shear is usually taken at about $\frac{3}{4}$ the safe horizontal stresses; or, for steel girders in buildings, about 11,000 lb. per sq. in. *In no case should the web be less than $\frac{5}{16}$ in. thick.*

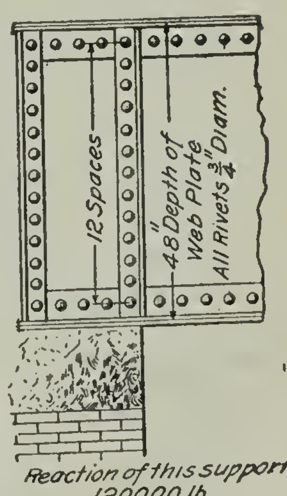


FIG 22.

EXAMPLE.—Fig. 22 shows the end of a girder, the greatest reaction being 120,000 lb.; with an allowable unit shearing stress of 11,000 lb., what should be the thickness of the web-plate?

SOLUTION.—The width of plate is 48 in., and there are 13 – $\frac{3}{4}$" rivet holes. Allowing $\frac{1}{8}$ in. for punching each hole, the net depth is 48 in. – ($\frac{7}{8}$ × 13) = $36\frac{5}{8}$ in. Applying the formula,

$$t = \frac{120{,}000}{36\frac{5}{8} \times 11{,}000} = .297 \text{ in.}$$

As this is less than $\frac{5}{16}$ in., the latter thickness is used.

Stiffeners.—Web-plates, besides resisting direct vertical shear, must resist buckling. To avoid failure by buckling before the full shearing strength of the plate is realized, stiffeners, composed of angles, as shown in Fig. 20, must be used. Some engineers require the use of stiffeners when the unit shear exceeds the unit stress allowed by the following formula:

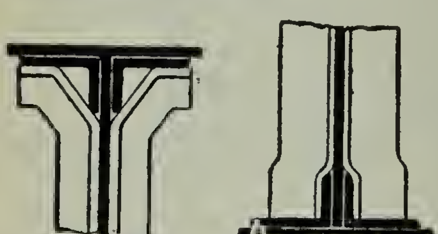
$$s = \frac{12{,}000}{1 + \frac{d^2}{3{,}000\,t^2}},$$

in which s = allowable unit stress;
d = depth of girder, between flanges, in inches;
t = thickness of web-plate in inches.

A more convenient rule provides *that stiffeners be used when the thickness is less than $\frac{1}{50}$ the clear distance between vertical legs of flange angles.* For example, in a girder with a $\frac{3}{8}'' \times 36''$ web and $6'' \times 6''$ flange angles, the distance between vertical legs of angles is $36 - (2 \times 6) = 24$ in.; $\frac{1}{50}$ of 24 in. = .48, say $\frac{1}{2}$ in.; the web-plates being but $\frac{3}{8}$ in. thick, stiffeners must be used.

Stiffeners should never be omitted over the end supports, and should be provided under all concentrated loads. The distance between centers of intermediate stiffeners is usually made equal to the depth of girder. Under no condition, however, should stiffeners be placed more than 5 ft. apart.

End stiffeners should be considered as columns transmitting the entire load upon the web to the supports. The size of intermediate stiffeners is not usually calculated; they are usually made the same size as the end ones, or lighter. Angles used for stiffeners should not be less than $3'' \times 3'' \times \frac{5}{16}''$; on shallow girders, however, with light loads, it might be economical to use $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{5}{16}''$ angles; but smaller ones should never be used. Stiffeners should extend over the vertical legs of the flange angles, being either swaged out to fit, as shown at (*a*) and (*b*), Fig. 23, or, preferably, provided with filling pieces, as shown in Fig. 20.



(*a*) (*b*)

FIG. 23.

EXAMPLE.—Using 4 end stiffeners (2 each side), and a safe unit compressive stress of 13,000 lb., what size angles should be used for stiffeners of the girder shown in Fig. 22.

SOLUTION.—The required sectional area is 120,000 ÷ 13,000 = 9.23 sq. in.; 9.23 sq. in. ÷ 4 = 2.31 sq. in., the area required for each angle. From Table XIV, a $4'' \times 4'' \times \frac{5}{16}''$ angle has a sectional area of 2.40 sq. in., which is ample.

Flanges.—The flanges of a girder—called top and bottom chords in open or lattice girders—include the flange plates and angles, as shown in Fig. 20. Frequently, one-sixth the sectional area of the web plate is included as part of each flange, although, in many cities, the building ordinance will not allow this to be done. If the sixth is so included, the web should never be spliced at the point of greatest bending, and all splices should be so designed that, by proper placing of the rivets, the strength of the web included in the one-sixth be reduced as little as possible.

In a simple girder, the top flange is subjected to compression, and the bottom one to tension. It is the practice, for economy in construction, to make the flanges alike, only the lower flange being calculated. The bottom flange being in tension, the area of the rivet holes are deducted, so that the net area at the point of least strength may be obtained.

The horizontal stresses on the flanges are resisted by the fibers in one flange acting with a moment about the center of gravity of the other. This moment is equal to their total strength multiplied by the distance between centers of gravity of the flanges. Thus, Fig. 24 shows a plate girder

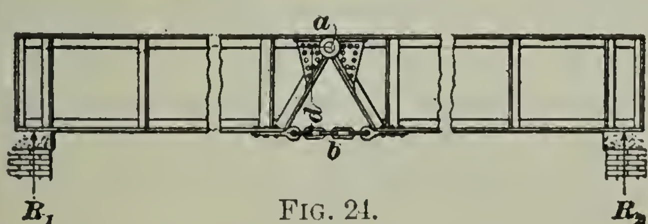


FIG. 24.

pin connected at a, and a chain in tension, representing the lower flange, at b. It is evident that the reactions tend to turn the girder about a, and rupture the chain, which resists

this tendency with a lever arm d equal to the distance between the centers of gravity of the flanges. The depth is, in practice, however, usually taken to be the depth of the web.

To find the net area of the lower flange, let M_1 be the resisting moment in foot-pounds; M, the bending moment in foot-pounds; s, the allowable unit tensile stress; a, the net area of flange in square inches; and d, the depth of girder in feet; then $s \times a \times d = M_1$, which must be equal to M; from which $a = \frac{M}{s \times d}$.

Rule.—*The net sectional area of the lower flange of a plate girder is equal to the greatest bending moment in foot-pounds divided by the product of the allowable unit tensile stress in pounds and the depth of the girder in feet.*

In proportioning the flanges, the sectional area of the flange plates should equal, approximately, that of the flange angles. This is not possible in heavy work, and the best that can be done is to use the heaviest sections obtainable for the flange angles.

EXAMPLE.—A steel girder is 6 ft. deep, and 80 ft. span, and the load 3,000 lb. per lineal foot. (a) What net flange area is required, using a safe unit tensile stress of 15,000 lb. per sq. in.? (b) Of what size sections should the flange be made?

SOLUTION.—(a) The entire load is $80 \times 3{,}000 = 240{,}000$ lb. From Table XXVI, page 113, the bending moment is

FIG. 25.

$$M = \frac{WL}{8} = \frac{240{,}000 \times 80}{8} = 2{,}400{,}000 \text{ ft.-lb.}$$

The net flange area

$$a = \frac{M}{s \times d} = \frac{2{,}400{,}000}{15{,}000 \times 6} = 26.6 \text{ sq. in.}$$

(b) Assume the section shown in Fig. 25. The area of a $6'' \times 6'' \times \frac{5}{8}''$ angle being, approximately, 7 sq. in., the sectional area of the flange is,

Two $6'' \times 6'' \times \frac{5}{8}''$ angles $= 7 \times 2 = 14.00$ sq. in.
Three $14'' \times \frac{7}{16}''$ plates $= 14 \times \frac{7}{16} \times 3 = 18.37$ sq. in.

Total $= 32.37$ sq. in.

From the total area deduct the metal cut out for rivet holes, which, taken as $\frac{1}{8}$ in. larger than the rivet, are 1 in. in

diameter. The web is not eonsidered in the flange seetion. The areas dedueted are, therefore,

Four 1″ holes through ⅝″ metal = $2\frac{1}{2}$ sq. in.
Two 1″ holes through $1\frac{15}{16}$″ metal = $3\frac{7}{8}$ sq. in.

Total = $6\frac{3}{8}$ sq. in.

The net area of the flange is 32.37 − 6.37 = 26 sq. in., whieh, although a little less than the net area required, 26.6 sq. in., eould be used.

Length of Flange Plates.—The bending moment on a simple beam varies throughout the length; and, to design girders eeonomically, the net flange area should vary with the bending moment. This eondition is fulfilled by using flange plates of different lengths, eaeh extending only as far as needed to provide the net seetion required. It is good praetiee to eontinue the inner plate the entire length of the girder, in order to stiffen it laterally. The lengths of flange plates in girders uniformly loaded may be obtained approximately by the formula:

$$L_1 = 2 + L\sqrt{\frac{a}{A}},$$

L_1 being the required length of the plate in feet; L, the length of girder in feet; a, the net seetional area of all plates to and ineluding the plate in question, beginning with outside one; and A, the total flange area. The 2 ft. is added to allow for riveting.

EXAMPLE.—Fig. 26 shows a flange seetion of a girder. The span being 60 ft., what should be the length of eaeh flange plate?

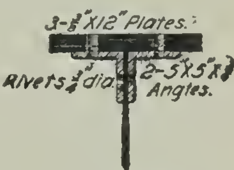


FIG. 26.

SOLUTION.—Area of a 5″ × 5″ × ¾″ angle (see Table XIV, page 85) is 7.11 sq. in. Area of eaeh plate is ⅜ in. × 12 in. = 4.5 sq. in.; the rivet holes are ¾ + ⅛ = ⅞ in., and the area eut out by a ⅞″ hole through a ⅜″ plate is .328 sq. in.; henee, the net area of eaeh plate is 4.5 sq. in. − (.328 sq. in. × 2) = 3.844 sq. in.; or, for 3 plates, 3.844 × 3 = 11.532 sq. in. The net area of the two angles is (7.11 sq. in. × 2) − (.656 × 4) = 11.596 sq. in. Therefore, the net area of flange will be 11.532 + 11.596 = 23.128 sq. in.

By the formula, the length of outside plate

$$L_1 = 2 + 60\sqrt{\frac{3.844}{23.128}} = 26.42, \text{ say } 26 \text{ ft. } 6 \text{ in.}$$

Similarly, the length of the intermediate plate

$$L_1 = 2 + 60\sqrt{\frac{7.688}{23.128}} = 36.56 \text{ ft., say } 36 \text{ ft. } 6 \text{ in.}$$

The inner plate is continued the entire length of the girder, so as to stiffen it laterally.

Fig. 27 shows a graphical method of finding the lengths of flange plates for a girder carrying any number of concentrated loads. Lay off $a\,b$ to any scale, equal to the span, and locate on it the point of application of each load, as c, d, and e. Having calculated the bending moment under each load, lay it off, to a convenient scale, on the corresponding perpendicular to $a\,b$, through c, d, and e, as $c\,f$, $d\,g$, and $e\,h$. Draw the lines $a\,f$, $f\,g$, $g\,h$, and $h\,b$. Divide $e\,h$, the line representing the greatest bending moment, into as many equal parts as there are square inches in the net section required. (For a method of dividing a space into equal parts, see *Geometrical Drawing*, page 55.) Take $e\,r$ equal to as many parts as there are square inches in the net sectional area of flange angles; also, $r\,s$ equal to net area of the first plate, etc. Draw parallels to $a\,b$ through r, s, t, etc. Make $i\,k$ equal to $a\,b$; where $i\,k$, etc. intersects $a\,f$ and $b\,h$, erect perpendiculars $p\,l$ and $q\,m$, etc. Then $l\,m$, measured to same scale as $a\,b$, is the length of the first flange plate; $n\,o$, that of the second, etc. *The lengths thus found should be increased 1 ft. at each end*, to allow for riveting.

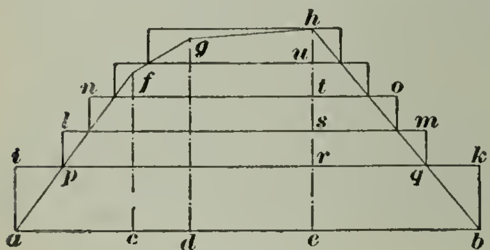


FIG. 27.

The lengths of plates for uniformly loaded girders may be similarly found. Having calculated the maximum bending moment, lay it off to scale, perpendicular to the middle of the span. The curve representing the bending moment is in this case a parabola, and may be drawn through the point

just named and the ends of the span, by the method given in *Geometrical Drawing* on page 58. The remainder of the work is like that shown in Fig. 27.

Rivet Spacing.—Enough rivets must be placed in the end stiffeners of girders to transmit the shear to the web. For example, 100,000 lb. is the reaction on a girder constructed as in Fig. 22; the web is $\frac{3}{8}$ in. thick, the rivets $\frac{7}{8}$ in. diam. The allowable unit bearing value being 15,000 lb. (by Table XXIX, page 131), the ordinary bearing of a $\frac{3}{8}''$ plate on a $\frac{7}{8}''$ rivet is 4,920 lb.; adding $\frac{1}{3}$ because the plate is web bearing, gives 6,560 lb. Since the double shearing value of the rivet is greater than the web-bearing value of the plate, 6,560 lb. must be taken as the resistance of one rivet. Then the number of rivets required in the two pairs of angles is 100,000 ÷ 6,560 = 15.2, say 16, or 8 rivets in each pair. Rivets in intermediate stiffeners are usually spaced the same as in end stiffeners, their spacing not being calculated. No rivets in stiffeners should be spaced more than 6 in. apart, or more than 16 times the thickness of the angle leg.

As the shear increases from the point of greatest bending towards the supports, the number of rivets placed in the vertical legs of the flange angles, to resist their tendency to slide on the web, must also increase as the supports are approached. The horizontal stress, per inch of length, which is transmitted from the web to the flange at any point, is equal to the maximum shear at any point divided by the depth of the girder in inches.

For example, in the girder shown in Fig. 28, the shear at a is R_1, or 100,000 lb.; at b, it is 100,000 lb. — (5,000 lb. × 4) = 80,000 lb., at c, 60,000 lb., etc. The horizontal stress per inch of length at a is 100,000 ÷ (4 × 12) = 2,083 lb.; at b, 80,000 ÷ 48 = 1,667 lb.; at c, 60,000 ÷ 48 = 1,250 lb.; at d, 833 lb., etc. Using $\frac{7}{8}''$ rivets, the safe bearing value of each is 6,560 lb. At a, the stress being 2,083 lb. per inch of run, the rivets should be placed 6,560 ÷ 2,083 = 3.14 in. center

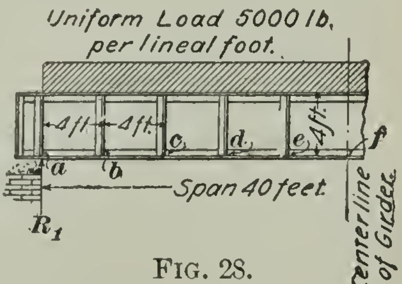


FIG. 28.

to center; at b, 6,560 ÷ 1,667 = 3.93 in.; at c, 6,560 ÷ 1,250 = 5.24 in.; at d, 6,560 ÷ 833 = 7.87 in. In practice, rivets are spaced alike in both flanges; and as 6 in. is the greatest allowable pitch in a compression member, further calculation is needless. The rivet spacing from a to b is, then, $3\frac{1}{4}$ in.; b to c, 4 in.; c to d, $5\frac{1}{4}$ in.; beyond d, as the theoretical pitch is more than 6 in., the 6-in. pitch should be used.

At the ends of each flange plate, sufficient rivets must be used, spaced $2\frac{1}{2}$ to 3 in. on centers, to transmit the allowable stress on the net section of the plate to the adjacent members. The remaining rivets should be spaced the greatest allowable pitch for a compression member, namely, 16 times the thickness of the thinnest outside plate—provided the pitch does not exceed 6 in. For example, in a $\frac{3}{8}'' \times 12''$ flange plate, after deducting the area of two 1″ holes ($\frac{7}{8}''$ rivets + $\frac{1}{8}''$), the net sectional area is $3\frac{3}{4}$ in. Assuming the safe unit fiber stress at 15,000 lb., 3.75 in. × 15,000 = 56,250 lb., strength of plate. The safe value of each rivet in this case will be taken at 5,410 lb.; then the number required in each end of the plate is 56,250 ÷ 5,410 = 10, say 5 each side of the web, and they should be spaced from $2\frac{1}{2}$ to 3 in. on centers. In splicing the lower flange angles, which are in tension, enough rivets should be placed therein to equal in resistance that of the net section of the angles. In splicing the top angles, since they are in compression, only enough rivets need be used to securely hold them in abutting position.

STRENGTH OF RIVETS AND PINS.

RIVETS.

In proportioning riveted joints, the friction between the plates caused by the clamping effect of the rivets is neglected. Hence, a riveted joint may fail in two ways, namely, by the shearing of the rivets, and by the crippling or crushing of the metal in the member around the rivet hole. It is necessary therefore, in designing a riveted joint, to consider, besides the shearing of the rivets, the bearing value of the plates or rolled sections.

The strength of a riveted joint also depends upon the distribution of the members connected, and the location of the rivets; that is, whether the rivets are in single or double shear, and the members connected in ordinary or web bearing.

A rivet may be in *single* shear, as at (a), or in *double* shear as shown at (b), in Fig. 29. At (a) the tendency is to shear the rivet along the line $a\,b$, and the strength of the rivet is equal to its *sectional area multiplied by the shearing strength of the material composing it.* At (b) the tendency is to shear the rivet along the lines $a\,b$ and $c\,d$; hence, the strength of the rivet in this case is twice that of the former, and is equal to *twice the sectional area of the rivet, multiplied by the shearing strength of the material* in the rivet.

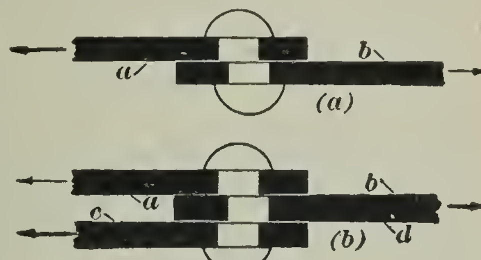


FIG. 29.

The plates or structural sections composing a joint tend to fail or cripple, as at a, Fig. 30. Hence, the bearing strength of a plate is equal to the *thickness of the plate multiplied by the diameter of the rivet and this product by the bearing strength of the material* composing the plates or rolled sections. Where the plate is situated, as at (b), Fig. 29, between two outside plates, the central plate is said to be subjected to *web bearing*, and it is usual to consider the value of this plate, in resisting bearing, to be a *third higher* than in ordinary bearing, as at (a).

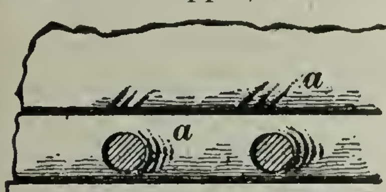


FIG. 30.

The most reliable test of steel and iron is the tensile, and the shearing and bearing values are deduced from it. Conservative practice takes shearing values for high-grade iron and steel at $\frac{3}{4}$ of the tensile strength of the material, and the ordinary bearing value at $1\frac{1}{2}$ times the tensile, while web bearing is taken at twice the tensile strength. On this basis the following table is formed:

TABLE XXVIII.

ALLOWABLE SHEAR AND BEARING VALUES.

Rivets.	Character of Work.	Pounds per Square Inch.		
		Shearing.	Ordinary Bearing.	Web Bearing.
Iron rivets	Railroad bridges	6,000	12,000	16,000
Iron rivets	Highway bridges and buildings	7,500	15,000	20,000
Steel rivets	Railroad bridges	7,500	15,000	20,000
Steel rivets	Highway bridges and buildings	9,000	18,000	24,000

It is therefore important, in designing riveted joints, to determine whether the shearing strength of the rivets or the bearing values of the plates is the stronger, and to proportion the joint accordingly.

Table XXIX gives the shearing and bearing values for the principal sizes of rivets and plates used in steel construction.

The greatest economy in material is obtained when the net area of the plates or members joined is the greatest possible; that is, when the percentage or ratio existing between the net section and the gross section is as great as can be. It is usual, in proportioning riveted work, where the rivets are driven by hand in the field, to increase the number of rivets 25 or 50 per cent. to allow for faulty riveting.

It has previously been said that rivets fail by shearing; they are, however, in rare instances liable to fail by bending. This occurs only when the rivets are long and it is impossible to drive them enough to have them upset sufficiently to fill the holes. In such case the only remedy is to so design the joint as to lessen the grip of the rivet, or increase the number of rivets, and consequently reduce the tendency to bending. Rivets are never proportioned to withstand flexure.

TABLE XXIX.

Shearing and Bearing Values of Rivets.

Diameter of Rivet. Inches.	Single Shear at 6,000 Lb. per Sq. In.	Bearing Value at 12,000 Lb. per Sq. In. for Different Thickness of Plate in Inches.						
		1/4	5/16	3/8	7/16	1/2	9/16	5/8
3/8	660	1,120						
1/2	1,180	1,500	1,880	2,250				
5/8	1,840	1,860	2,320	2,790	3,250	3,720		
3/4	2,650	2,250	2,810	3,370	3,940	4,500	5,060	
7/8	3,610	2,630	3,280	3,940	4,590	5,250	5,910	6,560
1	4,710	3,000	3,750	4,500	5,250	6,000	6,750	7,500

Diameter of Rivet. Inches.	Single Shear at 7,500 Lb. per Sq. In.	Bearing Value at 15,000 Lb. per Sq. In. for Different Thickness of Plate in Inches.						
		1/4	5/16	3/8	7/16	1/2	9/16	5/8
3/8	830	1,410						
1/2	1,470	1,880	2,340	2,810				
5/8	2,300	2,340	2,930	3,520	4,100			
3/4	3,310	2,810	3,520	4,220	4,920	5,630	6,330	
7/8	4,510	3,280	4,100	4,920	5,740	6,560	7,380	8,200
1	5,890	3,750	4,690	5,620	6,560	7,500	8,440	9,380

Diameter of Rivet. Inches.	Single Shear at 9,000 Lb. per Sq. In.	Bearing Value at 18,000 Lb. per Sq. In. for Different Thickness of Plate in Inches.						
		1/4	5/16	3/8	7/16	1/2	9/16	5/8
3/8	990	1,680						
1/2	1,770	2,250	2,820	3,370				
5/8	2,760	2,790	3,480	4,180	4,870	5,580		
3/4	3,970	3,370	4,210	5,050	5,910	6,750	7,590	
7/8	5,410	3,940	4,920	5,910	6,880	7,870	8,860	9,840
1	7,060	4,500	5,620	6,750	7,870	9,000	10,120	11,250

EXAMPLE.—Fig. 31 shows the riveted joint for a tension member. The allowable stress for the rivets in single shear is 7,500 lb. per sq. in., and the safe bearing and tensile values of the wrought-iron bars 15,000 and 12,000 lb. per sq. in., respectively; what will be the safe resisting strength of the member at the connection?

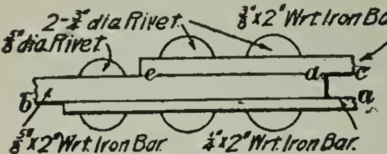


FIG. 31.

SOLUTION.—Determine whether the shear of the rivets, the bearing value of the bars, or the tensile strength of the members connected, is the strongest. The combined sections of bars *a* and *c* are equal to that of *b*. The safe tensile strength of members connected is equal to strength of net section of the bar *b*, obtained by deducting from the gross section of *b* the area of metal cut out for rivet holes. *The rivet hole is considered as ⅛ in. larger than the rivet, to compensate for the deterioration of the metal, due to punching.* The gross section is equal to ⅝ in. (thickness) × 2 in. (width) = 1.25 sq. in. The section of metal cut out for the rivet hole is equal to .625 in. × .875 in. (diameter of rivet hole) = .5468 sq. in.; the net section of the bar is therefore equal to 1.25 sq. in. — .5468 sq. in., or .7032 sq. in. The safe tensile strength of bar *b* is equal to .7032 sq. in. × 12,000 lb. (safe tensile strength per sq. in. of material) = 8,438 lb., which is also the combined strength of the bars *a* and *c*.

In Fig. 31 it is evident that the two ¾" rivets are in double shear along the lines *e d* and *b a*, but, by referring to Table XXIX, it will be seen that the safe bearing value of a ¾" rivet upon a ¼" plate is 2,810 lb., which is less than the safe shearing stress of the rivet, and is therefore the one to be used. The bearing value of the ¾" rivet upon the ⅜" bar *c* is greater than the shearing stress of the rivet; therefore, in this case the shear of the rivet should be taken as its resistance. The safe resistance of the ¾" rivets is then as follows:

Shear of two ¾" rivets on line *e d* =	3,310 × 2 =	6,620 lb.
Bearing value of two ¾" rivets on ¼" plate	2,810 × 2 =	5,620 lb.
	Total =	12,240 lb.

To this add the safe shearing stress of the $\frac{5}{8}''$ rivet, which is 2,300 lb., or less than its safe bearing value against the $\frac{1}{4}''$ bar. Thus, $12{,}240 + 2{,}300 = 14{,}540$ lb., the safe resistance of the rivets to shear, and the plates or bars to crippling. From these results, it is seen that the net section of the bars is weaker than the connection; hence, the safe strength of the tension member is 8,438 lb., the strength of bar *b*, or the combined strength of bars *a* and *c*.

Pitch of Rivets.—The least distance from center to center of rivets, or the *pitch*, should not be less than *3 times* the diameter of the rivet. If the members are in *tension*, the greatest pitch should not be more than 30 times the thickness of the thinnest outside plate or member. If the members are in *compression*, the pitch should not be more than 16 times the thickness of the thinnest outside plate or member. The pitch should never be greater than 6 in., except where the rivets are set zigzag, or *staggered*, in which case the pitch should not be more than 6 in. in a staggered line. The distance from the end of a plate to the center of a rivet should not be less than the thickness of the plate plus the diameter of the rivet plus $\frac{1}{8}$ in. The distance from the center of a rivet to the side of the plate should not be less than one-half the thickness of the plate plus one-half the diameter of the rivet plus $\frac{1}{8}$ in.

The sizes of rivets most commonly used in building construction are $\frac{3}{4}$ in. and $\frac{7}{8}$ in. diameter; $\frac{5}{8}$ in. are sometimes used in connections where there is but little strain. For economy, there should be, in any structure, as few different sizes of rivets as possible.

STRENGTH OF PINS.

In proportioning pin-connected joints, the shear of the pin and the bearing value of the connected plates should be considered in the same manner as was riveted joints. Pins, however, are subjected to bending stresses that are neglected in riveted work; pins should always be proportioned to withstand such bending stresses. Round pins should be considered as beams having a solid circular cross-section. The bending moment in inch-pounds should be determined in a similar manner as for any beam (see pages 107 to 120), and

the resisting moment of the section obtained, which may be calculated (see page 114), or obtained from Table XXX, which also gives the shearing and bearing values for different size pins.

EXAMPLE.—What size pin will be required to resist bending in the connection shown in Fig. 32?

SOLUTION.—The bending moment is 10,000 lb. × 6 in. = 60,000 in.-lb.

The proper size pin having the required resisting moment may be obtained from Table XXX, page 137, or calculated thus: The section modulus for a solid cylindrical section is, according to Table XII, page 83, $.0982\,d^3$. Since d, the diameter of pin, must be assumed, try $3\frac{1}{2}$ in.

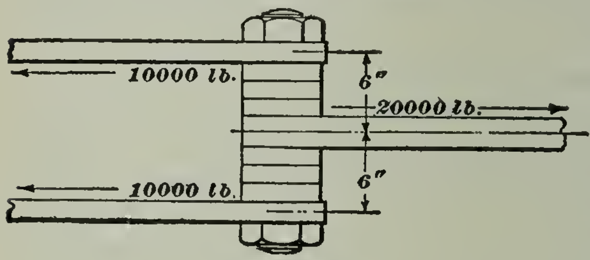


FIG. 32.

The section modulus is $.0982 \times 3\frac{1}{2} \times 3\frac{1}{2} \times 3\frac{1}{2}$, or 4.21. Then, as the safe resisting moment of any beam equals the section modulus multiplied by the safe stress of the material (see page 114), and assuming that the safe working stress of the material in the pin is 15,000 lb. per sq. in., the resisting moment is $4.21 \times 15,000 = 63,150$ in.-lb. Since the safe resisting moment must equal or exceed the bending moment (see page 108), a pin $3\frac{1}{2}$ in. in diameter will be sufficient to resist the bending stresses.

Where the lines of action of the stresses, in several members connected at a common joint by a pin, are inclined to one another, as at (a), Fig. 33, the stresses in the oblique members should be resolved into their vertical and horizontal components (see page 141). Having found these for all the forces acting upon the pin, the greatest bending moment due to all the vertical components, and that due to the horizontal components, should be obtained. Then, by adding the squares of these two amounts together and taking the square root of the result, the greatest resultant bending moment will be found.

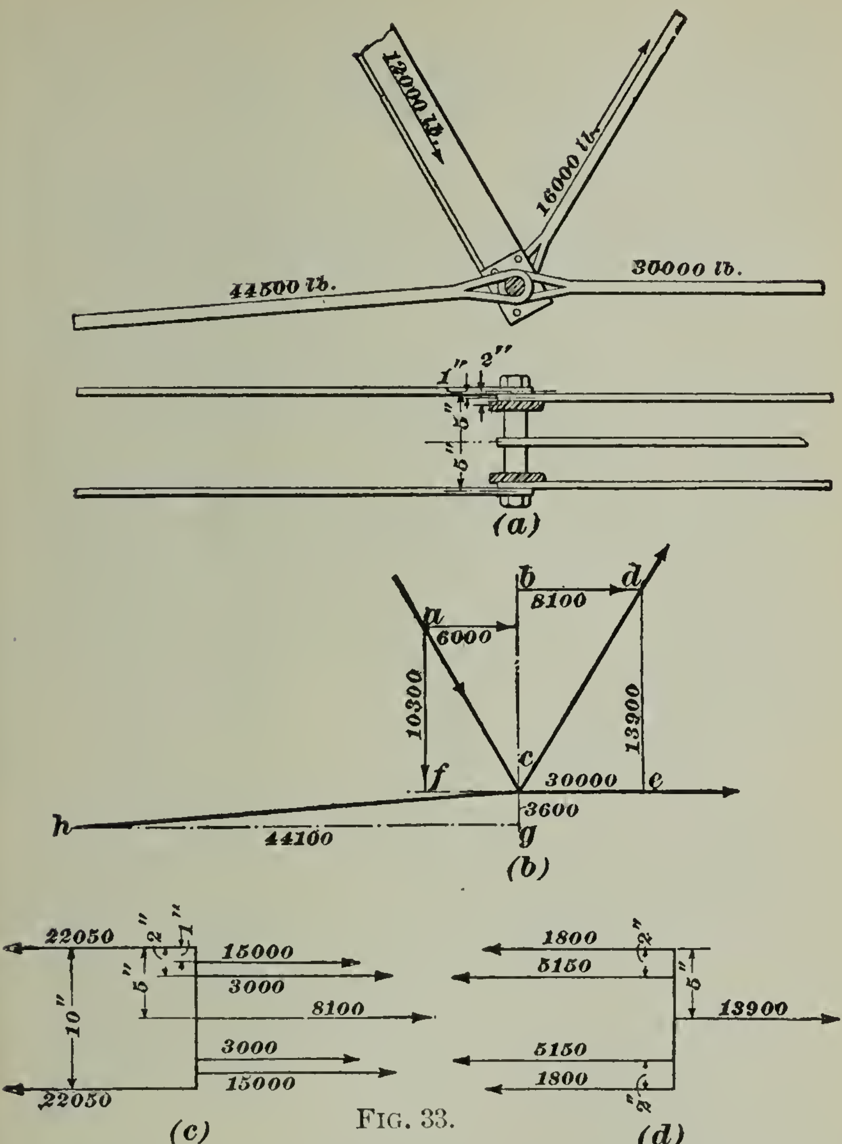


FIG. 33.

EXAMPLE.—Find the greatest resultant bending moment upon the pin shown at (*a*), Fig. 33.

SOLUTION.—Draw accurately the frame diagram, as at (*b*), Fig. 33, in which the full lines represent the direction of the members assembled at the joint. Lay off to some convenient

scale upon $c\,d$, a distance that will represent the stress in that member; then, by the principle of the parallelogram of forces, $d\,b$ will be the horizontal, and $d\,e$ the vertical, component of the stress in $c\,d$. Likewise, draw the horizontal and vertical components of the stresses in the members $c\,a$ and $c\,h$. Since the member $c\,e$ is horizontal, it will have no vertical component. The vertical and horizontal components of all the stresses in the oblique members may be obtained by scaling the lines which represent them. Since all the members except the right-hand oblique one are in pairs, one-half of each stress will be carried on each side of the center line.

Having obtained the amounts of the horizontal and vertical components, the diagrams (c) and (d) may be drawn. Care must be exercised to see that all the forces upon one side of the pin are equal to those upon the other; otherwise, the joint would not be in equilibrium, and would tend to move in the direction of the greater force. The diagram (c) shows the horizontal components of all the forces, the bending moment due to which is obtained as follows: (For bending moment see page 111.)

22,050 lb. × 5 in.		= 110,250 in.-lb.
deduct, 3,000 lb. × 3 in.	= 9,000 in.-lb.	
15,000 lb. × 4 in.	= 60,000 in.-lb.	69,000 in.-lb.
Total horizontal bending moment		= 41,250 in.-lb.

From the diagram (d) of all the vertical components the bending moment due to them is obtained thus:

1,800 lb. × 5 in.	= 9,000 in.-lb.
5,150 lb. × 3 in.	= 15,450 in.-lb.
Total vertical bending moment	= 24,450 in.-lb.

The resultant bending moment is, then:

$$\sqrt{41,250^2 + 24,450^2} = 47,900 \text{ in.-lb.}$$

From Table XXX, page 137, using a safe unit stress of 15,000 lb., it will be seen that a pin which is $3\frac{3}{16}$ in. in diameter has a resisting moment of 47,670 in-lb., which, while scant, will do.

If the pin is designed to resist bending, it is seldom necessary to consider the shear. The bearing values are found the same as for rivets, and are given in Table XXX.

TABLE XXX.

SHEARING AND BEARING VALUES AND MAXIMUM RESISTING MOMENTS OF PINS.

Diameter of Pin. Inches.	Maximum Resisting Moment.			Bearing Values for 1 Inch Thickness of Plate.			Shearing Values.		
	S = 15,000 Lb. Per Sq. In.	S = 18,000 Lb. Per Sq. In.	S = 22,500 Lb. Per Sq. In.	At 12,000 Lb. Per Sq. In.	At 15,000 Lb. Per Sq. In.	At 18,000 Lb. Per Sq. In.	At 7,500 Lb. per Sq. In.	At 9,000 Lb. per Sq. In.	At 11,250 Lb. per Sq. In.
$1\frac{7}{16}$	4,370	5,240	6,550	17,200	21,600	25,900	12,150	14,600	18,200
$1\frac{11}{16}$	7,070	8,480	10,610	20,200	25,300	30,400	16,800	20,200	25,200
$1\frac{15}{16}$	10,700	12,840	16,050	23,200	29,100	34,900	22,100	26,550	33,200
$2\frac{3}{16}$	15,400	18,480	23,110	26,200	32,800	39,400	28,200	33,800	42,300
$2\frac{7}{16}$	21,310	25,580	31,970	29,200	36,600	43,900	35,000	42,000	52,500
$2\frac{11}{16}$	28,570	34,280	42,850	32,200	40,300	48,400	42,500	51,000	63,800
$2\frac{15}{16}$	37,310	44,770	55,960	35,200	44,100	52,900	50,850	61,000	76,300
$3\frac{3}{16}$	47,670	57,200	71,508	38,200	47,800	57,400	59,850	71,800	89,800
$3\frac{7}{16}$	59,790	71,750	89,680	41,200	51,600	61,900	69,600	83,500	104,400
$3\frac{11}{16}$	73,810	88,570	110,710	44,200	55,300	66,400	80,100	96,100	120,150
$3\frac{15}{16}$	89,860	107,830	134,790	47,200	59,100	70,900	91,350	109,600	137,000
$4\frac{3}{8}$	123,300	147,960	185,000	52,500	65,600	78,750	112,700	135,300	169,100
$4\frac{5}{8}$	145,700	174,800	218,500	55,500	69,400	83,300	126,000	151,200	189,000
$4\frac{7}{8}$	170,600	204,700	255,900	58,500	73,100	87,750	140,000	167,900	209,900
$5\frac{3}{8}$	228,700	274,400	343,000	64,500	80,600	96,750	170,150	204,200	255,200
$5\frac{5}{8}$	262,100	314,500	393,100	67,500	84,400	101,250	187,000	224,000	280,000
$5\frac{7}{8}$	298,600	358,300	447,900	70,500	88,100	105,750	203,000	244,000	305,000
6	318,100	381,700	477,100	72,000	90,000	108,000	212,000	254,000	318,000

BOLTS AND TENSION BARS.

The strength of bolts in resisting shear and bending may be analyzed similarly to rivets and pins. When bolts or round bars threaded at the end are subjected to tensile stress, they tend to break at the weakest section, which is at the root of the screw thread. In order to make the threaded part equal in strength to that of the body of the rod, the end is sometimes *upset*, so that the diameter at the root of the thread will equal that of the body. Upsetting, however, requires more smithwork, the cost of which will likely be more than that of the additional material required to increase the size enough to make upset ends unnecessary.

The following table (XXXI) gives the principal dimensions for U. S. standard screw threads and nuts, and the area at the root of thread of any usual size rod. The strength of any tension rod may be found by multiplying this area by the tensile strength of the material.

EXAMPLE.—Required, the size of a threaded round tension rod, to sustain a stress of 13,350 lb., the safe working tensile stress of the material being 15,000 lb. per sq. in.

SOLUTION.—The area required is 13,350 lb. ÷ 15,000 lb. = .890 sq. in. at the root of the thread; from the table, it will be found that a rod $1\frac{1}{4}$ in. in diameter will suffice.

In designing tension bars it would be well to observe the following: Proportion the heads of eyebars so that the bar will break in the body instead of in the eye; the pin hole should be $\frac{1}{50}$ of an inch larger than the pin; all rivet holes in eyebars should be drilled and the wire edge cut off; bars should be thoroughly annealed after forging, and no smithwork should be done at a blue heat; small tension rods up to, say, $1\frac{3}{4}$ in. square are preferably, either simple loop or clevis rods; the eyes of loop rods should be bored to fit the pin; upset screw ends should have a net section at root of thread 15 per cent. greater than the body of the bar; steel rods may be used for upset screw ends, but should be tested in full size section, and thoroughly annealed after forging; clevises, twinbuckles, and sleeve nuts should be of standard approved pattern.

TABLE XXXI.

Bolts and Nuts.

Bolts. U. S. Standard Screw Thread.					Nuts. Manufacturers' Standard.			
					Hexagon.		Square.	
Diam. of Bolt. In.	No. of Threads per Inch.	Diam. at Root of Thread. Inches.	Area of Body of Bolt. Sq. In.	Area at Root of Thread. Sq. In.	Short Diam. Inches.	Long Diam. Inches.	Side of Square. (In.)	Diagonal. Inches.
$\frac{1}{4}$	20	.185	.049	.027	$\frac{1}{2}$	.58	$\frac{1}{2}$	.71
$\frac{5}{16}$	18	.240	.077	.045	$\frac{5}{8}$	.72	$\frac{5}{8}$	.88
$\frac{3}{8}$	16	.294	.110	.068	$\frac{3}{4}$	.87	$\frac{3}{4}$	1.06
$\frac{7}{16}$	14	.344	.150	.093	$\frac{7}{8}$	1.01	$\frac{7}{8}$	1.24
$\frac{1}{2}$	13	.400	.196	.126	1	1.15	1	1.41
$\frac{9}{16}$	12	.454	.249	.162	$1\frac{1}{8}$	1.30	$1\frac{1}{8}$	1.59
$\frac{5}{8}$	11	.507	.307	.201	$1\frac{1}{4}$	1.44	$1\frac{1}{4}$	1.77
$\frac{3}{4}$	10	.620	.442	.302	$1\frac{3}{8}$	1.59	$1\frac{1}{2}$	2.12
$\frac{7}{8}$	9	.731	.601	.419	$1\frac{5}{8}$	1.88	$1\frac{3}{4}$	2.47
1	8	.837	.785	.550	$1\frac{3}{4}$	2.02	2	2.83
$1\frac{1}{8}$	7	.940	.994	.694	2	2.31	$2\frac{1}{4}$	3.18
$1\frac{1}{4}$	7	1.060	1.230	.890	$2\frac{1}{4}$	2.60	$2\frac{1}{2}$	3.54
$1\frac{3}{8}$	6	1.160	1.480	1.060	$2\frac{1}{2}$	2.89	$2\frac{3}{4}$	3.89
$1\frac{1}{2}$	6	1.280	1.770	1.290	$2\frac{3}{4}$	3.18	3	4.24
$1\frac{5}{8}$	$5\frac{1}{2}$	1.390	2.070	1.510	3	3.46	$3\frac{1}{4}$	4.60
$1\frac{3}{4}$	5	1.490	2.400	1.740	$3\frac{1}{4}$	3.75	$3\frac{1}{2}$	4.95
$1\frac{7}{8}$	5	1.610	2.760	2.050	$3\frac{1}{2}$	4.04	$3\frac{3}{4}$	5.30
2	$4\frac{1}{2}$	1.710	3.140	2.300	$3\frac{1}{2}$	4.04	4	5.66
$2\frac{1}{4}$	$4\frac{1}{2}$	1.960	3.980	3.020	$3\frac{3}{4}$	4.33	$4\frac{1}{4}$	6.01
$2\frac{1}{2}$	4	2.170	4.910	3.710	$4\frac{1}{4}$	4.91	$4\frac{1}{2}$	6.36
$2\frac{3}{4}$	4	2.420	5.940	4.620	$4\frac{1}{2}$	5.20	$4\frac{3}{4}$	6.72
3	$3\frac{1}{2}$	2.630	7.070	5.430	$4\frac{3}{4}$	5.48	5	7.07
$3\frac{1}{4}$	$3\frac{1}{2}$	2.880	8.300	6.510	5	5.77	$5\frac{1}{2}$	7.78
$3\frac{1}{2}$	$3\frac{1}{4}$	3.100	9.620	7.550	$5\frac{1}{4}$	6.06	$5\frac{3}{4}$	8.13
$3\frac{3}{4}$	3	3.320	11.040	8.640	6	6.93	$6\frac{1}{2}$	9.19
4	3	3.570	12.570	10.000	$6\frac{1}{2}$	7.51	7	9.90
$4\frac{1}{2}$	$2\frac{3}{4}$	4.030	15.900	12.740	$7\frac{1}{2}$	8.58	8	11.31

The thickness of rough bolt heads, either hexagonal or square, is one-half the short diameter or side of square respectively; for rough nuts, it is equal to the diameter of the bolt. Finished heads and nuts have a thickness equal to the diameter of bolt less $\frac{1}{16}$ in.

ROOF TRUSSES.

PRINCIPLES OF STRESSES.

Paralle'ogram of Forces.—In Fig. 34, forces *a b* of 50 lb. and *c b* of 100 lb. act at *b* in the directions shown. To find their combined action, draw *c b*, to any scale, equal to 100 lb., and *a b* equal to 50 lb. Thus, if the scale is $\frac{1}{4}$ in. to 10 lb., *c b* = $2\frac{1}{2}$ in., and *a b* = $1\frac{1}{4}$ in. Draw *a d* parallel to *c b*, and *c d* to *a b*, intersecting at *d*; then *d b*, called the *resultant*, gives the direction, and, by scaling, the amount of their combined action, 145 lb. The figure *a b c d* forms a *parallelogram of forces*.

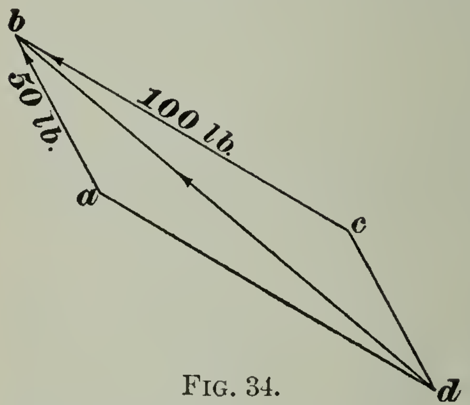


FIG. 34.

Triangle of Forces.—Assume forces *c a* of 1,000 lb., and *a b* of 800 lb., acting at *a*, Fig. 35. Make distance *c a*, to any scale, equal to 1,000 lb., and *a b* equal to 800 lb.; draw resultant *c b*, which, by scaling, is found to be 1,550 lb; it is opposed to the direction in which forces *c a* and *a b* act around the triangle. This figure *c a b* forms a *triangle of forces*.

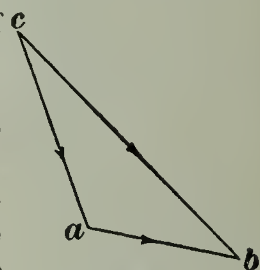


FIG. 35.

Polygon of Forces.—The preceding diagrams may be called *polygons of forces*, but the term is usually applied to diagrams determining the resultant of several forces. When a number of forces act as at *d*, Fig. 36, their resultant is obtained thus: Draw a line parallel to and having the same direction (as indicated by the arrow points) and magnitude as one of the forces. At the end of this line, draw one parallel to a second force, having the same direction and magnitude as this second force. Continue thus until all the forces have been plotted; a straight line joining the free ends of the

first and last lines will be the closing side of the polygon; mark it opposite in direction to the other forces, of which it will be the resultant. Thus, the resultant of the 4 forces acting at *d* is obtained by drawing *1–2*, *2–3*, *3–4*, *4–5*, parallel and equal to forces *a d*, *b d*, *c d*, and *e d*, respectively. Connecting *5* and *1*, the resultant is obtained.

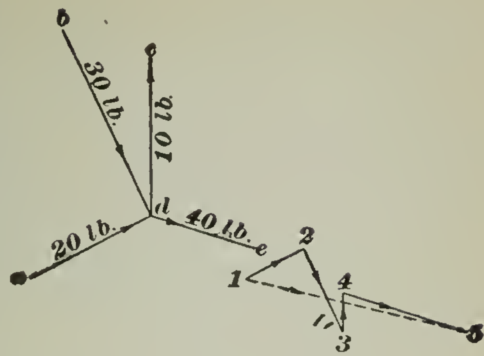


FIG. 36.

Resolution of Forces.—Since the effect of several forces may be determined by a single resultant, so may one force be resolved into several. For example, the force *a b*, Fig. 37, may be resolved into any two directions by drawing components parallel to those directions. Thus, from *a* draw *a c* vertically, and from *b* draw *c b* horizontally, intersecting at *c*; then *a c* is the *vertical component*, and *c b*, the *horizontal component* of *a b*.

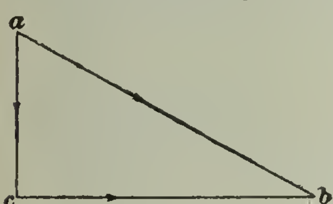
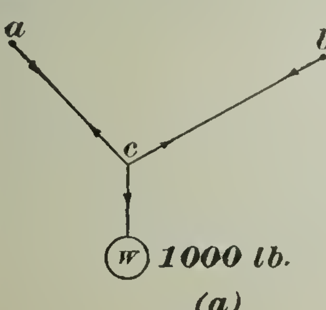


FIG. 37.

Frame and Stress Diagrams.—In (*a*), Fig. 38, 1,000 lb. is supported at *c* by cords *c a* and *c b*, secured at *a* and *b*. This figure, drawn



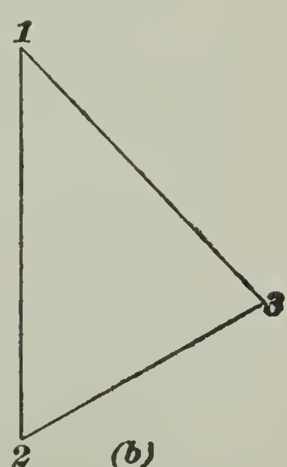


FIG. 38.

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to scale, accurately represents the outline of the structure, and is called a *frame diagram*. To obtain the stresses in $c\,a$ and $c\,b$, draw *1–2*, in (*b*), making its length to any scale and direction represent the magnitude and action of W. Thus, if 1 in. = 400 lb., *1–2* = $2\frac{1}{2}$ in. long, and, its direction being vertical in (*a*), it is so drawn in (*b*). From *1* draw *1–3* parallel to $a\,c$, and from *2* draw *2–3* parallel to $c\,b$; they intersect at *3*, forming with *1–2* a triangle. If *1–3* and *2–3* are measured, using same scale as for *1–2*, the stresses $c\,a$ and $c\,b$ may be obtained. Diagram (*b*) is called a *stress diagram*.

STRESSES IN ROOF TRUSSES.

In designing roof trusses, two stress and two frame diagrams are generally drawn, one of each for the dead loads, which act vertically, and the others for wind loads, usually taken as normal to the slope.

That the frame and stress diagrams may be conveniently compared, the following system of lettering may be employed: In the frame diagram, write capital letters within every space that is cut off from the rest of the figure by lines, real or

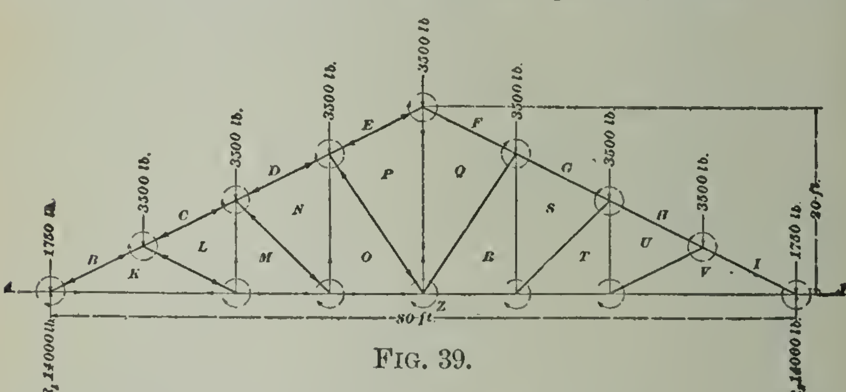


FIG. 39.

imaginary, along which forces act, as in Fig. 39. Then the member is named from the letters of the space it divides; thus, $B\,K$ designates the lower quarter of the left-hand rafter; $M\,L$, the first vertical tension rod from the left, etc. The stresses in these members are designated by similar small letters in the stress diagram; thus, the stress in $B\,K$ is $b\,k$ in Fig. 40, and in $M\,L$ is $m\,l$. It is to be understood that

wherever capital letters are used, reference is made to the frame diagram; and where small letters are used, reference is made to the stress diagram.

Analysis of Howe Roof Truss.—*Vertical-Load Diagrams.*—To explain the above principles in laying out stress diagrams for roof trusses, and the determination of the amount and kind of stress in any member, the vertical and wind-stress diagrams will be drawn for a Howe roof truss, Fig. 39; this shows the frame diagram with the vertical loads, which may be figured from Table I, page 62. Since the loads are equal and symmetrically placed, each reaction will be one-half the total load. Letter the frame diagram as shown, and proceed with the stress diagram, Fig. 40. The external forces, which include loads and reactions, having been determined (this should be done in every case), draw the load line aj vertically, as that is the direction in which the forces act. With any convenient scale, make $a\,b$, $b\,c$, $c\,d$, etc. equal, respectively, to the calculated forces $A\,B$, $B\,C$, $C\,D$, etc. The reactions $J\,Z$ and $Z\,A$, being equal, z is located midway between j and a. Then the *polygon* of *external forces*, as it is called, is from a to b, b to c, c to d, d to e, and so on to j, where the reactions return on the load line from j to z, and from z to a, the starting point. It will be observed from this that, though a straight line has been drawn, in reality a many-sided polygon has been traced, each external force constituting a side.

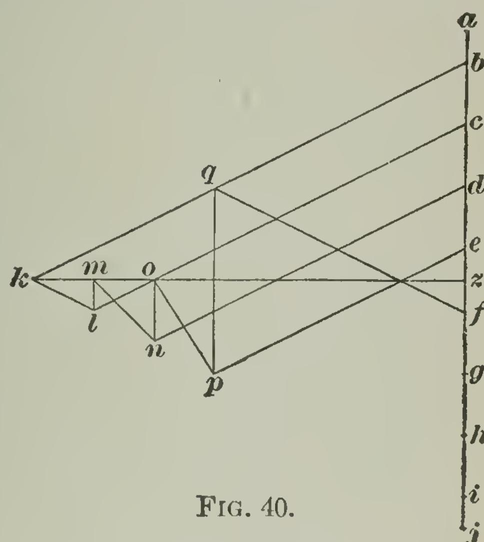


FIG. 40.

The internal forces, or the stresses in the truss members, may now be determined, as follows: Beginning at the left-hand joint in the frame diagram, the forces are $B\,K$, $K\,Z$, $Z\,A$, and $A\,B$. Care must be taken, in reading these forces, to go

around each joint in the same direction in which the external forces were designated. From b draw $b\,k$ parallel to $B\,K$, and from z draw $z\,k$ parallel to $K\,Z$; their intersection is at k, and the polygon of forces around the joint is from a to b, b to k, k to z, and z to a, the starting point. After having designated all the forces at a joint in the stress diagram, always read around the polygon of forces as given above, and see that it *closes*, that is, that the last line joins the first, forming a closed figure. Also, note the direction in which the forces travel along each line in the stress diagram, and mark the same by arrowheads upon the members in the frame diagram. Arrowheads acting away from a joint, as in $K\,Z$, denote tension; those acting towards one, as in $B\,K$, denote compression.

The next joint is $B\,C\,L\,K$, and the lines determining the stresses are obtained by drawing, from c, $c\,l$ parallel to $C\,L$, and, from k, $l\,k$ parallel to $L\,K$; their intersection is at l, and the polygon of forces around this joint is from c to l, l to k, k to b, and b to c, the starting point. In similar manner the stresses around any joint may be obtained.

When the apex joint is reached, the diagram begins to repeat; thus, $f\,q$ is the same as $e\,p$. It is therefore unnecessary to proceed further, as the loads being symmetrically placed, the stresses in the right half of the truss will be identical with those on the left half.

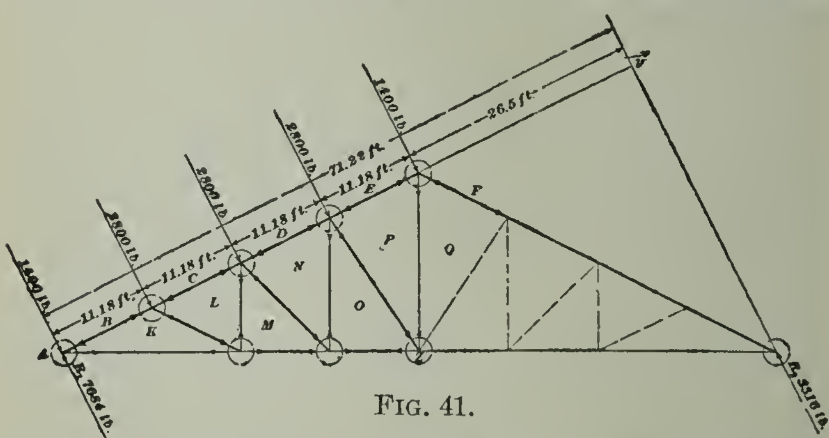


FIG. 41.

Wind-Load Diagrams.—To determine the wind stresses, the

frame diagram should be redrawn. The wind loads, considered as acting at each *panel point*, may be determined from Table VII, page 68, and are shown in Fig. 41. As the ends of the truss are secured against sliding, the reactions act parallel to the wind pressures. If, however, the left end of the truss is secured, and the right end rests on rollers (as is sometimes the case with iron or steel trusses to permit expansion), the right reaction, instead of being parallel to the direction of the wind, would be vertical. The wind-stress diagram for such a truss would, with this exception, be found similarly to that for a fixed-end truss.

To determine reactions R_1 and R_2, let R_1 be the center of moments; then the perpendicular distance between the line of action of R_2 and the point R_1 is 71.22 ft., obtained by extending the left-hand rafter to intersect the line of action of R_2 at y'. Regard $A y'$ as a beam, and calculate reactions R_1 and R_2 by the method given for beams. Taking moments about R_1, the reaction R_2 is found to be 3,516 lb.; and R_1 = 11,200 lb., the total load, $-$3,516 lb. = 7,684 lb.

Proceed with the wind-stress diagram, Fig. 42, by drawing the load line af parallel to the direction of the wind in the frame diagram. Lay off to any scale the forces ab, bc, cd, etc., equal to AB, BC, CD, etc., respectively. Then, from a lay off az, equal to reaction ZA, or R_1. If the loads have been laid off accurately, fz should be equal to R_2.

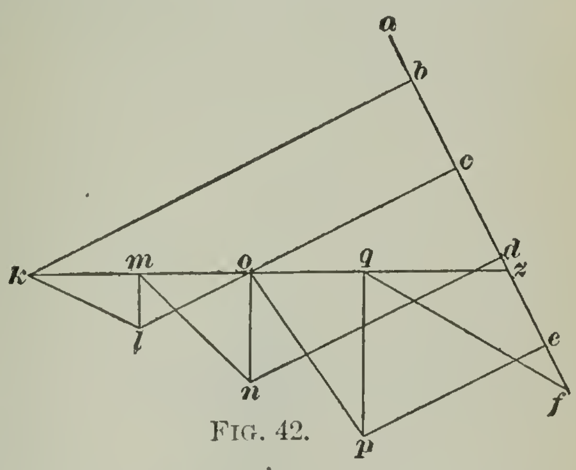


FIG. 42.

The first joint to analyze is $ABKZ$. Draw bk parallel to BK; and from z, zk parallel to KZ; they intersect at k. The polygon of forces is from a to b, b to k, k to z, and z to the starting point a. Joint $BCLK$ is analyzed similarly.

To analyze joint $KLMZ$: kl being known, the next member is LM; from l draw lm, parallel to LM. As the next member is MZ, to which mz is parallel, the point m is located where lm intersects mz; this completes this joint, the polygon of forces being from k to l, l to m, m to z, and z to k. The stresses at the other joints may be found in the same way as those explained. The members shown in dotted lines do not sustain wind stresses when the wind blows upon the left side of the truss.

The final joint is $EFQP$, at which there is only one unknown force—the stress in FQ. A line drawn from f parallel to FQ should pass through q. This is always a test of the accuracy of the work, and if the last line does not close on the proper point, when drawn parallel to the member it represents, the stress diagram should be redrawn, to determine whether the loads and reactions have been laid out correctly, and whether any joint or member has been omitted.

The two diagrams completed, scale, in round numbers, the stresses in each member, indicating compressive and tensile stresses by plus and minus signs, respectively. Tabulate results as follows:

Member.	Vertical Load. Pounds.	Wind Load. Pounds.	Total. Pounds.
BK	+ 27,000	+ 12,000	+ 39,000
CL	+ 23,500	+ 10,000	+ 33,500
DN	+ 19,500	+ 7,600	+ 27,100
EP	+ 16,000	+ 5,680	+ 21,680
KZ	— 24,000	— 13,300	— 37,300
MZ	— 21,000	— 10,000	— 31,000
OZ	— 17,500	— 7,000	— 24,500
LK	+ 4,000	+ 3,500	+ 7,500
NM	+ 5,000	+ 4,400	+ 9,400
PO	+ 6,500	+ 5,400	+ 11,900
ML	— 1,600	1,500	— 3,100
ON	— 3,500	— 3,000	— 6,500
QP	— 10,600	— 4,500	— 15,100
FQ	+ 16,000	+ 6,600	+ 22,600

Analysis of Stresses in a Fink Roof Truss.—This truss, shown in Fig. 43, is much used for pin-connected and structural-steel trusses.

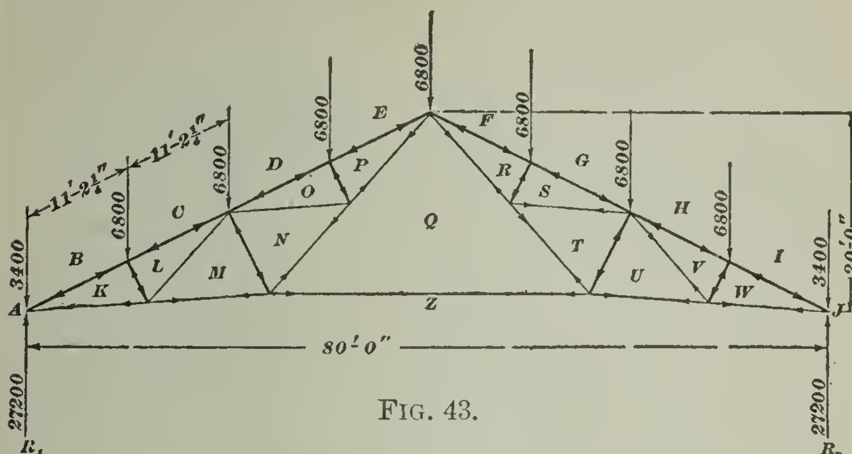


FIG. 43.

Vertical-Load Diagrams.—Obtain the forces acting at each panel point and draw the frame diagram for the vertical loads, as in Fig. 43. Since the loading is symmetrical, the reactions R_1 and R_2 will each be one-half the load, or 27,200 lb. Draw in the stress diagram, Fig. 44, the load line $a\,b\,c\,d\,e$, etc., locating z midway between e and f. The polygon of external forces will be from a to b, b to c, c to d, etc., until j is reached; retracing the load line from j to z gives R_2, and from z to a determines R_1.

Analyzing each joint as before shown, no difficulty will be met until the joints $C\,D\,O\,N\,M\,L$ and $M\,N\,Q\,Z$ are reached; it is found that three unknown forces exist at each of these joints, and, as it is impracticable to determine the stresses graphically when more than two forces are unknown, the value of one must be otherwise obtained. Upon inspecting the frame diagram, it will be observed that the joint at $B\,C$ is

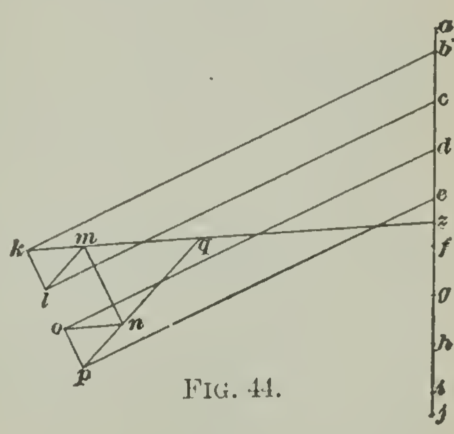


FIG. 44.

similar to $D E$; and it is reasonable to suppose that $L K$ will have an equal stress with $P O$. From this it would appear that there must be an equal and like stress exerted by $L M$, to retain the foot of $L K$ in position, as is exerted by $O N$ to keep $P O$ in place. The stresses in $M L$ and $L C$ being known, that in $D O$ may be determined by drawing a line from d parallel to $D O$, to such a point o that—having drawn $o n$ equal in length to $l m$—the line $n m$, parallel to $N M$, will close on m. The polygon of forces will be from m to l, l to c, c to d, d to o, o to n, and n to m, the starting point.

The joint $M N Q Z$ now offers no difficulty to solution, as $m n$ has been previously determined. The final joint $O P Q N$ may be solved by drawing from p a line parallel to $P Q$, which will, if the diagrams have been correctly drawn, pass through n, and from this point will coincide with $n q$.

One half the vertical-load diagram being completed, and the loading being symmetrical, it is unnecessary to draw the

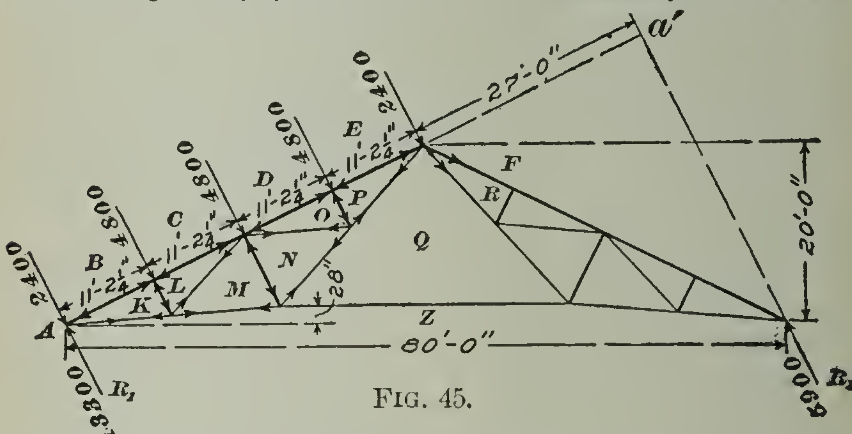


FIG. 45.

other half unless as a check. The equality of the triangles $l k m$ and $p o n$, and their resemblance to $n m q$, greatly assist in drawing diagrams for trusses of this type.

Method of Trial for Obtaining Third Unknown.—If one unknown stress prevents the solution of the diagram, it may sometimes be found by trial. Thus, assume the amount of unknown stress and proceed with diagram; if it fails to close, again assume amount of unknown stress and try. Proceed thus until diagram closes.

Wind-Stress Diagrams.—First find the external forces and reactions, as in the Howe truss, page 143, and redraw the frame diagram, as in Fig. 45. The solution of the wind-stress diagram, Fig. 46, offers the same difficulties as in drawing the vertical-load diagram, and may be similarly solved. The last joint $FRQPE$ is solved by drawing from f a line parallel to FR, and from q, a line parallel to RQ; their intersection is at r, and the polygon of forces is from e to f, f to r, r to q, q to p, and p to e.

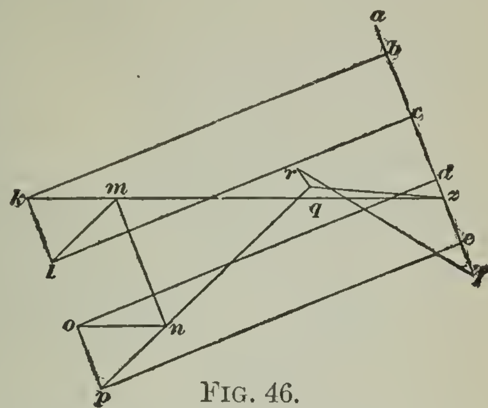


FIG. 46.

DETAIL DESIGN OF ROOF TRUSSES.

Trusses subjected to wind, acting perpendicular to the gable, should be braced with diagonal braces connecting the several trusses. If, however, the roof sheathing is of planking secured directly to the trusses, and especially if run diagonally, other bracing may not be required. If stone gables protect the roof in a longitudinal direction, lateral bracing may in many cases be omitted.

The vertical and wind loads of a truss may be figured from Tables I, VII, pages 62, 68. The weight of the truss is the most uncertain factor, being practically unascertainable until the design is made; hence, it is well, after designing the truss, to calculate and compare its weight with that assumed.

The stresses being determined, the members must be proportioned to sustain them. Roof trusses differ from bridge trusses in that the loads are generally statical and not suddenly applied; consequently, a smaller factor of safety may be employed. It is the practice, in ordinary construction, to employ for timber members in a roof truss a

factor of safety of from 4 to 6; and for structural steel and wrought iron, 3 to 4; cast iron is seldom used in roof trusses, and is never used with a factor of safety less than 10, unless the load creates compressive stress only, in which case a somewhat smaller factor may be used. The factor of safety

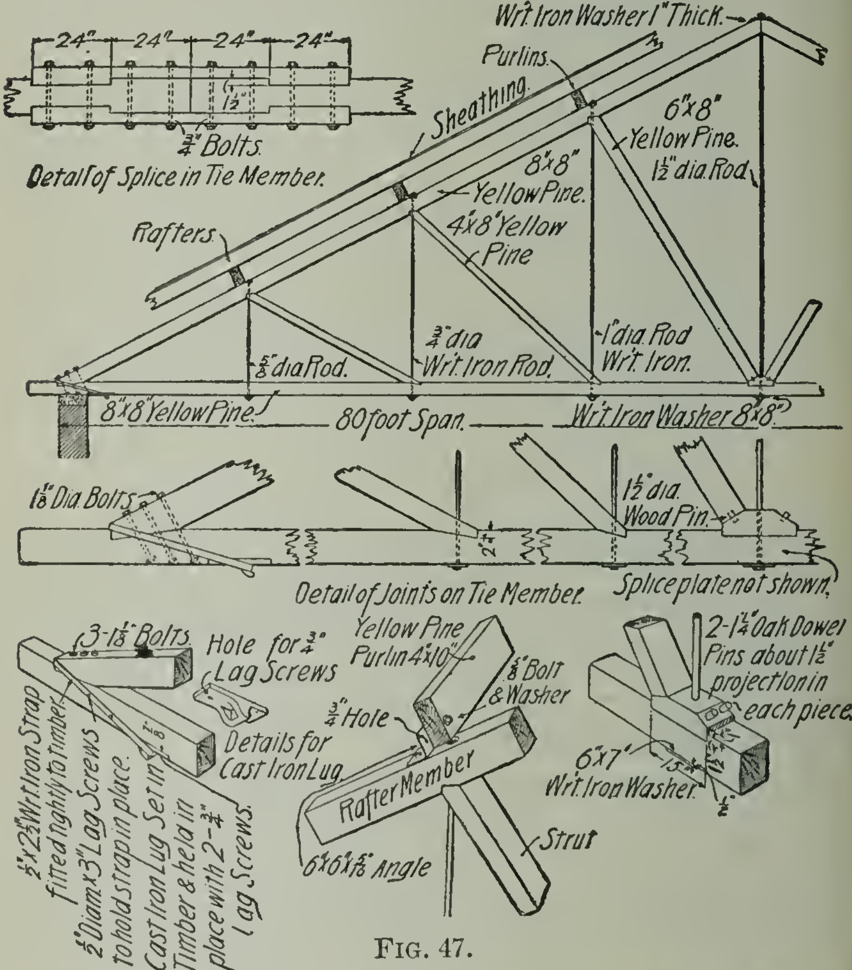


FIG. 47.

is much a matter of judgment, and may be altered as the designer's experience dictates.

Tension members are liable to fail at the least cross-section; therefore, the screw ends of long rods and bolts should be enlarged, so that the cross-section at the root of the threads will be at least as large as elsewhere. Allowance

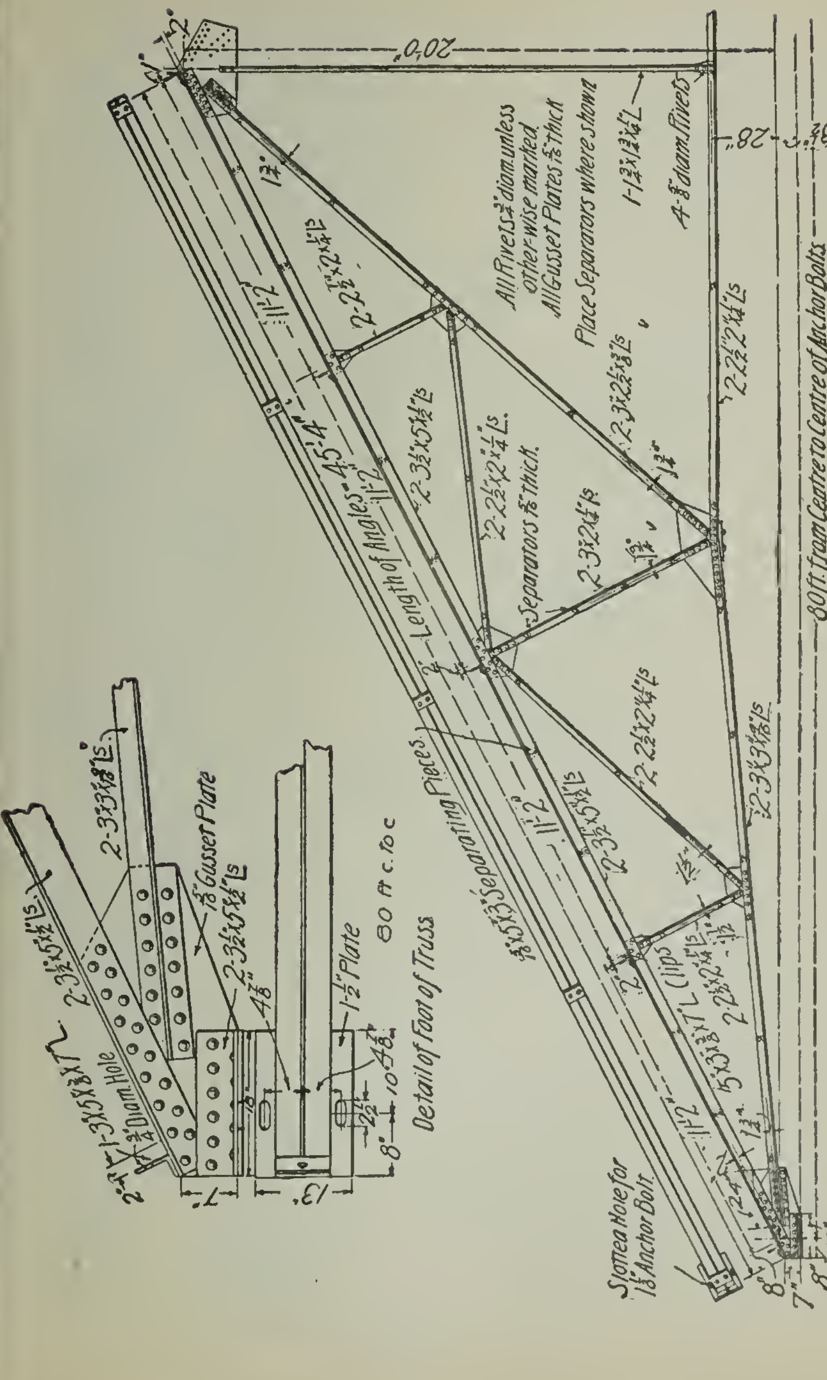
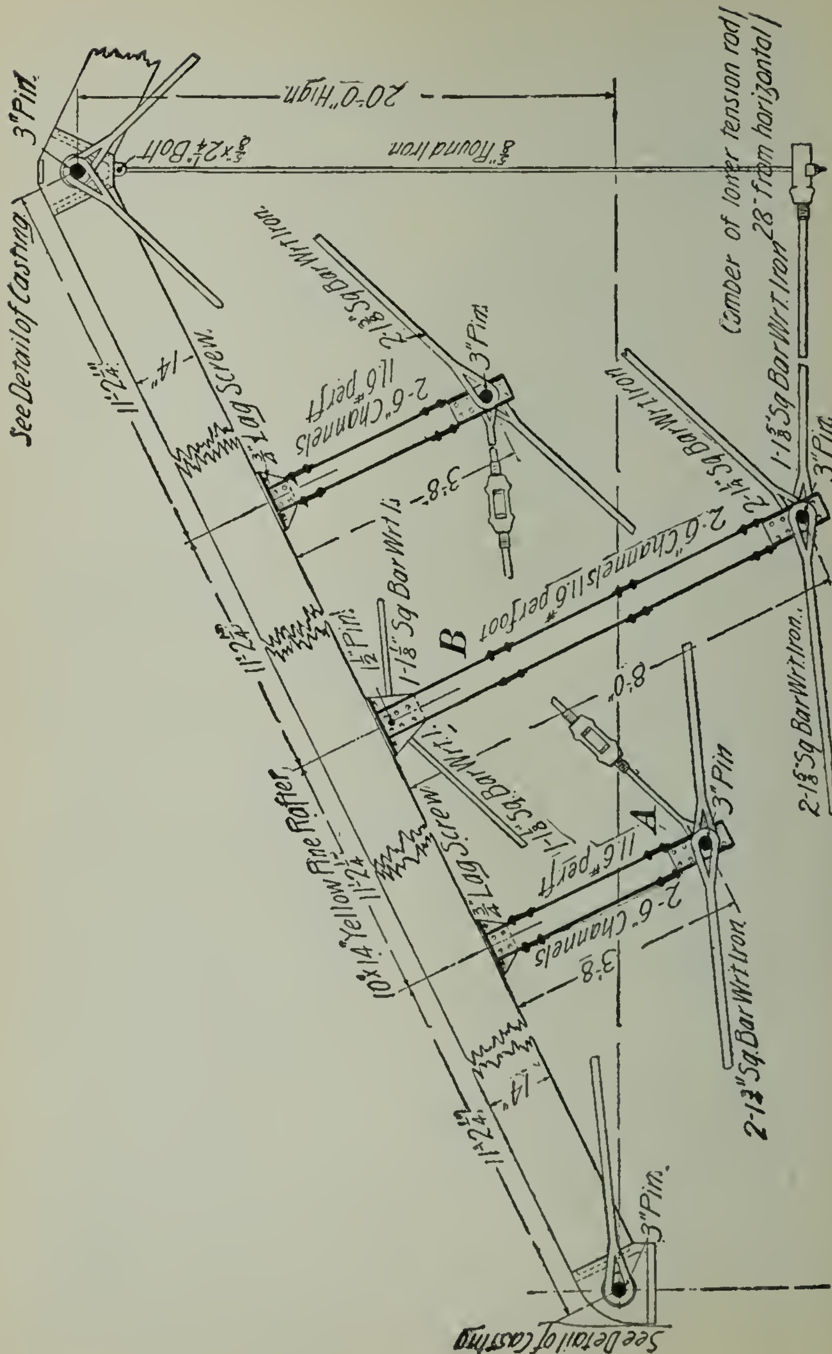

All Rivets ¾" diam. unless other-wise marked. All Gusset Plates ⅜" thick
Place Separators where shown
Length of Angles 45'-4"
Separators ⅜" thick.
Separating Pieces
4-⅝" diam. Rivets
20'-0"
80 ft. from Centre to Centre of Anchor Bolts
Slotted Hole for 1⅛" Anchor Bolt.
Detail of Foot of Truss
80 ft c. to c
1-½" Plate
⅜" Gusset Plate

FIG. 48.



3"Pin.
20'-0" High
5/8"x2 1/4" Bolt
5/8" Round Iron
Camber of lower tension rod
28" from horizontal
See Detail of Casting.
11'-2 1/4"
-14"-
Lag Screw.
2-1 1/8" Sq Bar Wrt Iron
3"Pin
2-6" Channels
11.6# per ft
3/4" Lag
3'-8"
1-1/8" Sq Bar Wrt I
2-1 1/4" Sq Bar Wrt Iron
1-1 5/8" Sq Bar Wrt Iron
2-1 1/4" Sq Bar Wrt Iron
3"Pin
2-6" Channels 11.6# per foot
B
1 1/2" Pin
8'-0"
10"x14" Yellow Pine Rafter
1-1/8" Sq Bar Wrt I
A
3"Pin
2-1 5/8" Sq Bar Wrt Iron.
3/4" Lag Screw
2-6" Channels
11.6# per ft
3'-8"
2-1 3/4" Sq. Bar Wrt Iron
-14"-
3"Pin.
See Detail of Casting

FIG. 49. (a)

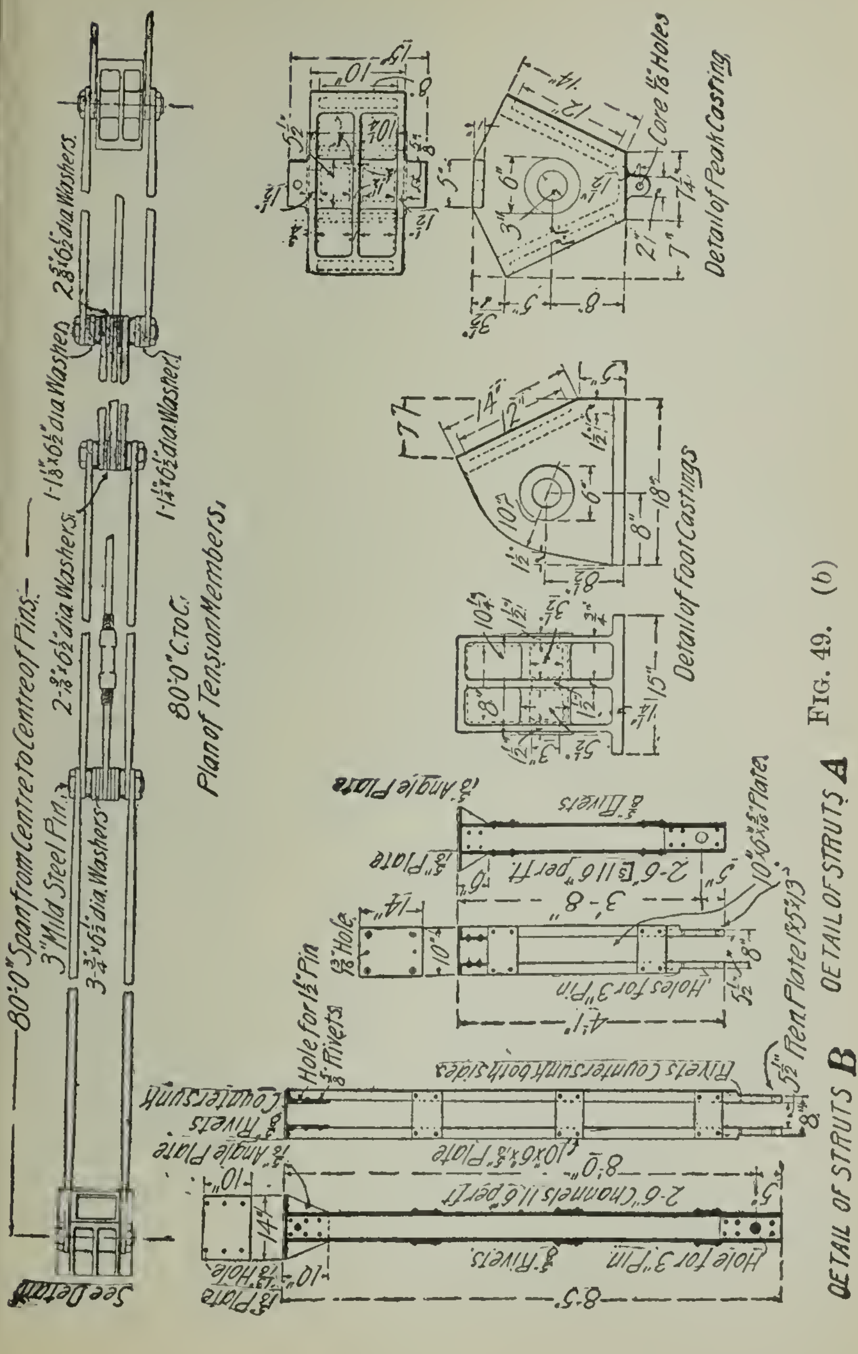

80'-0" Span from Centre to Centre of Pins.
3" Mild Steel Pin.
2-⅞"×6½" dia. Washers.
1-1⅛"×6½" dia. Washer.
1-1¼"×6½" dia. Washer.
2-⅝"×6½" dia. Washers.
3-¾"×6½" dia. Washers.
80'-0" C. to C.
Plan of Tension Members.
See Detail
Detail of Peak Casting
Core 1⅜" Holes
Detail of Foot Castings
DETAIL OF STRUTS A
DETAIL OF STRUTS B
2-6" Channels 11.6 per ft.
2-6" [11.6" per ft.
Hole for 3" Pin
Holes for 3" Pin
Hole for 1⅜" Pin
⅝" Rivets
Rivets Countersunk both sides
Fillet Plate
Angle Plate
10"×6"×⅝" Plate

FIG. 49. (b)

must be made for diminution of cross-section by bolt or rivet holes. To determine the net section required in any tension member, divide the stress upon the member by the allowable tensile stress of the material.

In proportioning compression members, the length of which is not over from 8 to 10 times the diameter or least side, the cross-section may be figured by dividing the stress by the allowable direct unit compressive stress. If, however, the length exceeds these dimensions, the members must be regarded as columns, and figured as such. If a member is subjected alternately to compression and tension, its section should be somewhat increased over that required to sustain either stress.

Where the rafter members of a truss support purlins between the panel points, the members are subjected to bending, as well as to direct compressive stress. In designing them, it is customary, with wooden members, to proportion them by first determining the proper size of beams to sustain the transverse stress, and adding sufficient sectional area, by increasing the width, to sustain the direct compressive or tensile stress, as the case may be. Where the direct stress is compressive, it should be also checked by applying the column formulas. Structural-steel or wrought-iron members are usually proportioned for the bending stress, the direct stresses being provided for by increasing the thickness of the rolled section, care being taken that the sum of the extreme transverse-fiber stress and direct-fiber stress is not more than the safe stress of the material.

Where members are connected by bolts or pins, the pins are usually proportioned to sustain the transverse stresses, and, if so proportioned, generally have sufficient resistance to shearing. Strength of pins is treated on pages 133–137, and the information given there will be found sufficient. Since the direct stresses in members connected at a common joint by a pin creates bending stresses upon the pin, the members should be packed closely, and those members having opposite stresses brought in juxtaposition if possible.

In designing any structure, and especially roof trusses, the following points should be carefully observed: (*a*) Propor-

tion all parts of a joint so that the maximum strength will be realized throughout, in order that one part will not be likely to yield before another. (*b*) Weaken as little as possible the pieces connected at a splice. (*c*) Give sufficient bearing surface to bring the compression on the surface well within the safe limits, so that there will be no danger of crippling plates or crushing the ends of members before their maximum strength is realized. (*d*) Distribute rivets and bolts so as to give the greatest resistance with the least cutting away of other parts. (*e*) See that the central axis of every member coincides as nearly as possible with the line of action of the stress. (*f*) Examine all sections and parts for tensile, compressive, transverse, and shearing stresses. (*g*) Finally, bear constantly in mind that the strength of a structure depends on the strength of its weakest part, and that the failure of a single joint may be as fatal to the life of a structure as though a member were insufficient.

A close study of the details of the trusses shown in Figs. 47, 48 and 49, in connection with the foregoing explanations of principles, will give a general idea of how such parts are designed.

ARCHES.

Principles.—Let P_1 and P_2, in Fig. 50 (*a*), represent the resultants of all the loads on the left and right halves of the arch, respectively, and let P_1 be equal to P_2, and located equally distant from the crown. Let R_1 and R_2 represent the vertical reactions, which, since the loads are symmetrically placed, are equal. Let b be the horizontal distance

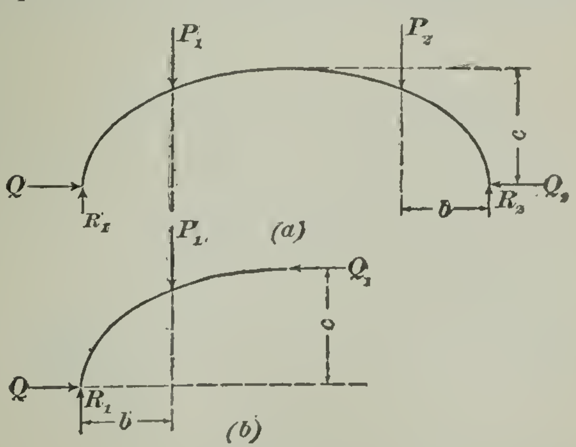


FIG. 50.

between R_1 and P_1; also between R_2 and P_2, or, in other words, the leverage of P_1 and P_2 with respect to R_1 and R_2. Let Q be the horizontal thrust, which is equal at all points; also, let c be the leverage of Q with respect to the crown. Now assume the right-hand half of the arch to be taken away, as in (b). To preserve equilibrium in the left side, the force Q_1 must be supplied at the crown. The algebraic sum of the vertical forces, and, likewise, the sum of the horizontal forces, must equal zero, or there will not be equilibrium. Then R_1 must equal P_1, and Q_1 must equal Q. Also, the sum of the moments about any point must equal zero. Hence, taking moments about the abutments in (a), $Q\,c = P_1\,b$, and $Q = \frac{P_1\,b}{c}$; also, since the arch is symmetrically loaded, $Q_2\,c = \frac{P_2\,b}{c}$ and $\frac{P_1\,b}{c} = \frac{P_2\,b}{c}$. In this case P_1 or P_2 may represent any number of loads, provided they are equal and symmetrically placed.

METHODS OF DETERMINING THE LINE OF PRESSURE.

Line of Pressure.—If a cord, fastened at each end, supports a number of loads, it will take a position of equilibrium, depending on the amount and location of the loads, as in (a), Fig. 51. In such a case, the cord is in tension. If the system is inverted, it will assume the position shown in (b), in which the forces are still in equilibrium; but, instead of a cord in tension, the lines $o\,p$, $p\,q$, etc. must be members capable of resisting compression. This latter case

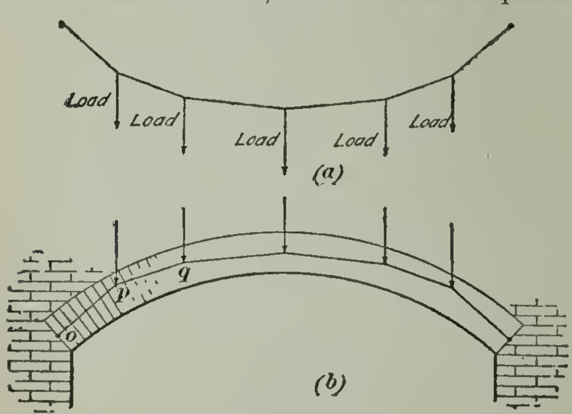


FIG. 51.

represents what exists in an arch, and the broken line intersecting the vertical forces forms the *line of pressure;* the material in the arch must be of such strength and so disposed as to safely resist the compressive forces acting along this line.

To determine the line of pressure for any arch, points at the abutments and crown must be fixed upon; otherwise, an indefinite number of lines of pressure could be drawn. In metal arches, the abutments and crown are generally hinged, or pin-connected, and the line of pressure necessarily passes through these three points. In masonry arches the abutments and crown are generally not hinged, although there are exceptions; and, therefore, a point must be assumed at each abutment and at the crown, through which the line of pressure is to pass. The line of pressure should, for a masonry arch, be within the middle third of the arch ring, the depth of keystone of which is first assumed, or made equal to that of some existing arch of about the same span. Thus, with an arch 3 ft. deep, the line of pressure should be within a space 6 in. on either side of the center of the depth. If it lies without the middle third, the joints tend to open, which result, while the danger of failure of the arch may not be great, would be unsightly. Again, if the line of pressure passes through the middle third, the angle that it makes with any joint will not be such that the voussoirs are likely to slide on their surface of contact.

In taking the loads upon arches, all weights must be reduced to the same standard; that is, in this case, the loads have been made equivalent to masonry weighing 140 lb. per cu. ft. The arch and loads are assumed to be 1 ft. in thickness, so that all superficial measurements also represent cubic contents.

Analytic Method.—In the arch shown in Fig. 52 (a), the pressure curve is considered as passing through points at the abutments $\frac{1}{3}$ the depth of the voussoirs from the intrados, and through the center of depth at the crown. The theoretical rise of the arch is 10.75 ft., and the theoretical span, 51.32 ft. The arch and load is divided by dotted lines into sections, which, for convenience, are numbered.

If w be the width of any section, and h its height, then its area a is $w \times h$. Also, if c is the distance from the crown to the center of gravity of a section, the moment m of any section about the crown is $a \times c$. Call A the sum of all the a's from the crown up to and including the section

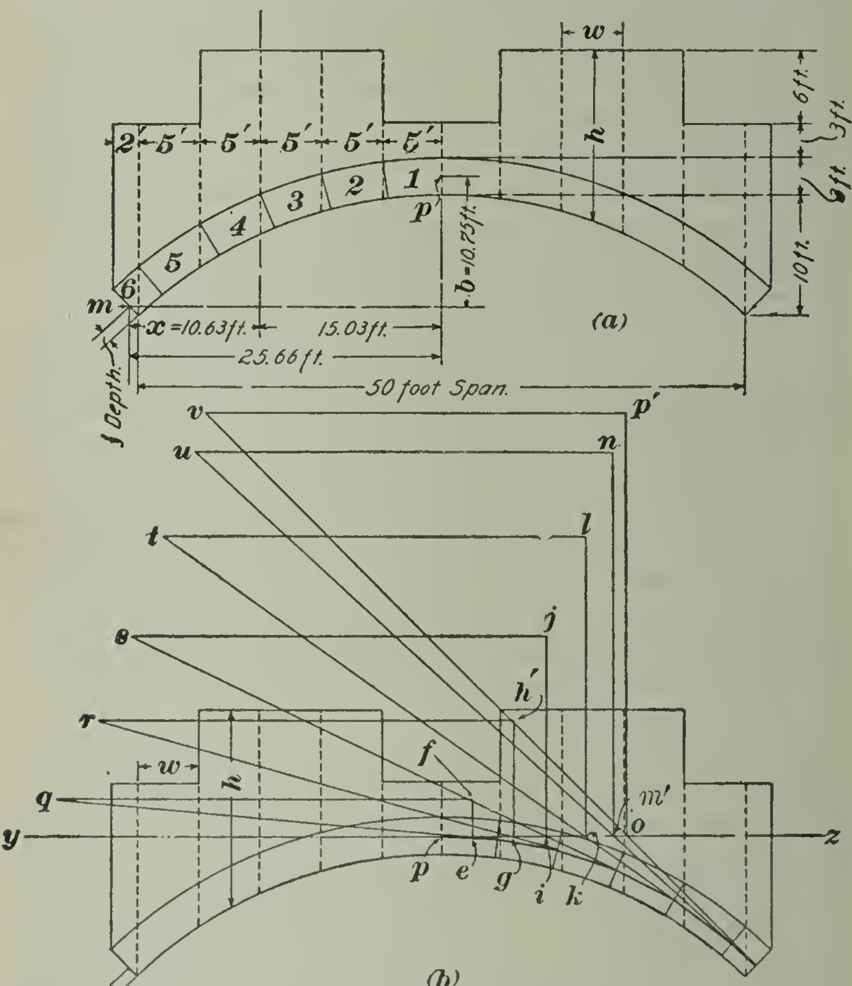


FIG. 52.

considered; thus, A for section 3 is, in the following table, $31.25 + 63.75 + 70$. Call M the total of the m's; thus, M for section 3 is $78.12 + 478.12 + 875$. Then, the distance C from the crown to the center of gravity of the portion between

the crown and the section considered is $\frac{M}{A}$ of that section (see *Neutral Axis*, page 75); thus, for section 3, the distance C for the portion including the sections 1, 2, and 3 is $\frac{1,431.24}{165} = 8.67$ ft.

The above values may be tabulated as follows:

Section.	w	h	$a = w \times h$	c	$m = a \times c$	$A = \Sigma a$	$M = \Sigma m$	$C = \frac{M}{A}$
1	5	6.25	31.25	2.5	78.12	31.25	78.12	2.50
2	5	12.75	63.75	7.5	478.12	95.00	556.24	5.85
3	5	14.00	70.00	12.5	875.00	165.00	1,431.24	8.67
4	5	16.50	82.50	17.5	1,443.75	247.50	2,874.99	11.61
5	5	14.00	70.00	22.5	1,575.00	317.50	4,449.99	14.01
6	2	14.75	29.50	26.0	767.00	347.00	5,216.99	15.03

The horizontal thrust, $Q = \frac{x \times P}{b}$, in which x is equal to one-half the theoretical span, or 25.66 ft. minus the value of C for the 6th section, which is, in this case, 15.03, giving $x = 10.63$; P is equal to A for the last section, 347; and b equals the theoretical rise of the arch, 10.75 ft. Hence, taking moments about m, $Q = \frac{x \times P}{b} = \frac{10.63 \times 347}{10.75}$, or 343 cu. ft. Multiplying by 140 lb., the weight of masonry per cubic foot assumed in this case, the horizontal thrust is 48,020 lb.

The line of pressure may now be determined as follows: Draw through point p in Fig. 52 (b), the horizontal line yz; lay off to scale from p, in order, the distances C obtained from table. At these points lay off the vertical distance ef, gh', ij, etc., equal respectively to the values 31.25, 95, 165, etc., from the column headed A. For instance, if the diagram is drawn to a scale of 1 in. to 100 cu. ft., the distance ef will be .31, or nearly $\frac{1}{3}$ in. From f, h', j, etc., to the same scale, mark off the constant horizontal thrust Q, as at fq, $h'r$, js, etc. Thus,

the vertical and horizontal forces at each section being given, the resultant of these two forces in each case is *e q*, *g r*, *i s*, etc. Extending each until it intersects the joint beyond *e*, *g*, *i*, etc., the pressure curve may be drawn through these latter points of intersection, as shown by the heavy black line, and the thrust at the joints may be found by measuring *e q*, *g r*, *i s*, etc. with the scale to which the diagram was drawn.

Since in this case the pressure curve falls well within the middle third of the arch ring, the arch may be considered satisfactory, provided the safe crushing strength of the masonry is not exceeded.

The influence of the last oblique thrust, which is the resultant thrust of the arch upon the pier, or abutment, will be explained in the following method of determining the pressure curve. This method is somewhat simpler, as it requires practically no calculations.

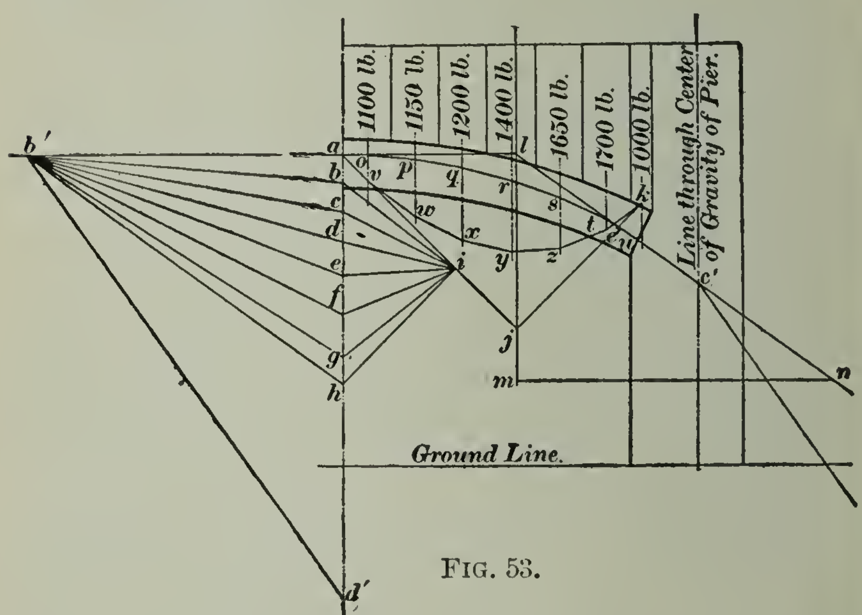


FIG. 53.

Graphic Method.—Fig. 53 shows the wholly graphic method of finding the line of pressure. It is for a 6-rowlock brick segmental arch, 24 ft. span, 2 ft. 10 in. rise, and 26 ft. radius of intrados.

Begin by drawing, to scale, a diagram of one-half the arch. As in the previous example, the arch and its load is considered to be 1 ft. thick; and the brickwork weighs 140 lb. per cu. ft. A load of 9,200 lb. upon one-half the arch has been assumed. Lay off, to scale, a height of brickwork whose weight will represent this load. Commencing at the crown, divide the load into, say, sections of 2 ft., as far as possible. The weight of each slice will be its contents multiplied by 140 lb., and is marked on the diagram. Next, fix a point at the crown, and one at the spring of the arch, through which the pressure curve is assumed to pass. The points may lie anywhere within the middle third of the width; but the point *a* at the crown has been taken at the outer edge, and the point *u* at the spring at the inner edge, of the middle third. Lay off from *a*, on the vertical *a d′*, the distances *a b*, *b c*, *c d*, etc., which represent the weight of the slices from the crown to the spring. Thus, if the scale were 1 in. per 1,000 lb., *a b* would be 1.1 in. long. Next, draw 45° lines from *a* and *h*, intersecting at *i*; and from *i* draw *i b*, *i c*, *i d*, etc. Through the center of gravity of each slice, draw a vertical, as *o v*, *p w*, *q x*, etc. Starting from *a*, draw *a v* parallel to *a i*; from *v*, draw *v w* parallel to *b i*, etc. These lines form a broken line, which changes its direction on the vertical line through the center of gravity of each slice. From the last point *k*, draw *k j* parallel to *i h*, and intersecting *a i*, extended, at *j*; from *j* draw a vertical line *j l*, which will pass through the center of gravity of the half arch and load. From *l*, where the horizontal line *a l* intersects *l j*, lay off a distance *l m* equal to *a h*, which represents the weight of all the slices. From *l* draw a line through the point *u*; and from *m*, a horizontal line intersecting *l u*, extended, at *n*. Then *m n* will be the horizontal thrust at the crown, required to maintain the half arch in equilibrium when the other half is removed; and *l n* will be the direction and amount of the oblique thrust at the skewback. On *l a* extended, lay off, from *a*, a distance *a b′* equal to *m n*. From *b′*, draw lines to *b*, *c*, *d*, etc., which represent the thrusts at the center of gravity of each slice. From *a*, draw *a o*, parallel to *b′ a*; from *o*, draw *o p*, parallel to *b′ b*, etc.; then *a*, *o*, *p*, etc. will be points on the

line of pressure. If this line lies within the middle third, the arch will be stable, provided the pressure is within safe limits. The pressure at u is found by measuring $b'\,h$ with the same scale as for $a\,b$, $b\,c$, etc., and is about 16,000 lb. Hard-burned brick, laid in cement mortar, will safely sustain a compressive stress of from 150 to 200 lb. per sq. in. The area at the skewback, 144 sq. in., multiplied by 200, gives 28,800 lb., which is well within the safe limit.

The stability of the abutments may be determined thus: Having calculated the weight of the pier or wall, lay off this weight on the vertical line from h to d', and draw $d'\,b'$. Draw a vertical line through the center of gravity of the pier, cutting $l\,n$ at c'; also, a line from c', parallel to $b'\,d'$. The latter line will be the resultant thrust of the arch, after being influenced by the weight of the pier. If this line falls beyond the foot of the pier, at the ground line, the pier will be incapable of resisting the thrust of the arch. In order that a pier may be secure, this final or resultant line of thrust should fall on the ground line, well within the middle third of the base.

MASONRY.

MATERIALS OF CONSTRUCTION.

STONE.

Granite is the most valuable stone where strength is required, its crushing strength averaging about 20,000 lb. per sq. in. Owing to its hardness, it is very costly to dress, and its use is limited to the most expensive kinds of buildings. Granite being very dense and compact, absorbs but little water, and hence is valuable in damp situations. Exposed to fire, it disintegrates at a temperature of from 900° to 1,000° F., being less durable in this respect than fine-grained compact sandstones. The average weight of granite is about 167 lb. per cu. ft.

Limestone is a very common building stone, and, when compact, is very durable. It is usually quite absorptive, and

becomes dirty quickly; while under intense heat, it is converted into lime. Limestone must be well seasoned before use, to get rid of the quarry water. The strength of limestone varies from 7,000 to 25,000 lb. per sq. in., the average being about 15,000 lb. The weight of limestone is about 155 to 160 lb. per cu. ft.

Sandstone is, in general, an excellent building stone, capable of resisting great heat, and the better kinds absorb only small quantities of water. The dark-brown, flinty sandstones retain their color very well, ranking better than granite. A stone containing much pyrites becomes unevenly discolored, due to formation of rust, and hence the stone should be carefully examined in this respect. The average strength of sandstones is about 11,000 lb. per sq. in., varying from 4,000 to 17,000 lb. The weight of sandstone is about 140 lb. per cu. ft.

The densest and strongest stones are generally the most durable. A fresh fracture, when examined under a magnifying glass, should be clear and bright, showing well-cemented particles. When a good stone is tapped with a hammer, it gives out a ringing sound. The absorptive quality of a stone may be tested by noting the increase in weight after soaking in water for 24 hours. One that increases 5 per cent. or more should not be used. For ordinary building purposes, tests of crushing strength are unnecessary, as if stone is of good quality the strength is generally very much in excess of any probable loads.

BRICK.

Brick should be sound, free from cracks or flaws, stones, or lumps. They should be of uniform size, with sharp edges and angles, and true and square surfaces. If two good brick are struck together, they give out a ringing sound; while if the sound is dull, the brick is of inferior quality. A good brick will not absorb more than 10 per cent. of its weight of water; the best will not absorb over 5 per cent., while soft brick will take up from 25 to 35 per cent.

The crushing strength of good quality brick should not be

less than 4,000 lb. per sq. in. Most good brick will have 2 or 3 times this strength. The weight of a common brick is about $4\frac{1}{2}$ lb., or 118 lb. per cu. ft.; pressed brick of the same size will weigh 5 lb. each, or 131 lb. per cu. ft.

The size of brick is variable, as shown by the following table. The standard brick, adopted by several associations of builders and makers, is $8\frac{1}{4}'' \times 4'' \times 2\frac{1}{4}''$ for common brick, and $8\frac{3}{8}'' \times 4\frac{1}{8}'' \times 2\frac{1}{4}''$ for face brick.

SIZE OF BRICK.

Name.	Thickness. Inches.	Width. Inches.	Length. Inches.
Common brick	$2-2\frac{1}{4}$	4	$8\frac{1}{4}$
Philadelphia pressed	$2\frac{1}{4}$	4	$8\frac{3}{16}$
Peerless Brick Co.	$2\frac{3}{8}$	$4\frac{1}{2}$	$8\frac{3}{8}$
Baltimore and Trenton	$2\frac{3}{8}$	$4\frac{1}{8}$	$8\frac{1}{4}$
Croton	$2\frac{1}{4}$	4	$8\frac{1}{2}$
Colabaugh	$2\frac{3}{8}$	$3\frac{5}{8}$	$8\frac{1}{4}$
Maine common	$2\frac{3}{8}$	$3\frac{3}{8}$	$7\frac{1}{2}$
North River common	$2\frac{1}{4}$	$3\frac{1}{2}$	8
Milwaukee	$2\frac{3}{8}$	$4\frac{1}{8}$	$8\frac{1}{2}$
Stourbridge firebrick	$2\frac{3}{8}$	$4\frac{5}{8}$	$9\frac{1}{8}$

TERRA COTTA.

All pieces of terra cotta for external work should be tested before use. They should emit a metallic sound when struck, and a fracture should show close texture and uniform color. The surface should be hard enough to resist a knife scratch, and the glazing should not be chipped off. Solid terra cotta weighs about 120 lb. per cu. ft., while hollow pieces of ordinary size average from 65 to 85 lb. The safe working strength of terra-cotta blocks in walls is about 5 tons per sq. ft., if unfilled, and 10 tons, if filled solid with concrete.

LIME.

When properly burned, quicklime should possess the following qualities: It should be in lumps, free from cinders, and with little or no dust; it should slake readily in water to

a smooth, impalpable paste, without residue; and it should dissolve in soft water if enough is added.

Lime weighs about 66 lb. per bu., or about 53 lb. per cu. ft. One barrel of lime, weighing 230 lb., will make about 2¼ bbl., or .3 cu. yd. of stiff paste. In 1-to-3 mortar, 1 bbl. of unslaked lime will make about 6¾ bbl. of mortar; or 1 bbl. of lime paste will make about 3 bbl. of mortar. For a 1-to-2 mortar, about 1 bbl. of quicklime to 5 or 5½ bbl. of sand are used.

CEMENTS.

The two kinds of hydraulic cements are termed Portland and natural (often called Rosendale, from a place in New York where much of it is made). The former is prepared by mixing together suitable proportions of clay and carbonate of lime, finely pulverized, and burning the mixture at a high heat in kilns, after which the mass is ground to a fine powder. Natural cements are so called because they are made from the natural rock, which contain the clay and limestone in the proper proportions.

Portland cements are dark in color, weigh from 90 to 100 lb. per cu. ft., are very slow in setting, and attain great ultimate strength. Natural cements are light in color, weigh from 50 to 60 lb. per cu. ft., are very quick setting, and become from ½ to ⅔ as strong as Portland cement.

A barrel of Portland cement weighs about 375 lb. net; one of the Eastern Rosendales, 300 lb., and Western Rosendales (from Wisconsin, Kentucky, Illinois, etc.), about 265 lb. A cubic foot of slightly compacted cement mixed with ⅓ cu. ft. of water will make from ⅔ to ¾ cu. ft. of paste; or 1 bbl. of cement will make about 3¾ cu. ft. of stiff paste.

Simple Cement Tests.—Mix a handful of the cement to be tested with water, and make it into two cakes about ½ in. thick, with thin edges. Let one dry in air for an hour and then put it in water for 24 hours, the other being kept in air. If at the expiration of that time the latter has become quite hard, and when broken shows considerable tensile strength, with a clean, sharp fracture, without crumbling, and the cake in water retains its shape and has become much harder, such

a cement is probably amply good for all building purposes. If the cake kept in water shows bad checks or cracks on the edges, such cement is unsafe to use under water, for any important work. If the sample in air becomes quite hard, while that under water crumbles, the cement may often be improved by mixing about half as much slaked lime with it. If it then hardens, it may be used in wet situations. The rapidity of setting in air may often be retarded, if required, by the addition of a small quantity of slaked lime. A cement which remains soft in air and does not become hard in water in 24 hours, may be a good cement for some purposes, but is very slow setting and undesirable for use in damp positions.

Tensile Strength.—When a testing machine is available, tests of tensile strength of cements are usually made. The following table indicates the average strength of cement mortars of various ages and compositions:

TENSILE STRENGTH OF CEMENT MORTARS.

Age of Mortar When Tested.	Average Tensile Strength. Pounds Per Square Inch.			
	Portland.		Rosendale.	
	Min.	Max.	Min.	Max.
Clear Cement.				
1 day, 1 hour, or until set, in air	100	140	40	80
1 week	250	550	60	100
4 weeks	350	700	100	150
1 year	450	800	300	400
1 Part Cement to 1 Part Sand.				
1 week			30	50
4 weeks			50	80
1 year			200	300
1 Part Cement to 3 Parts Sand.				
1 week	80	125		
4 weeks	100	200		
1 year	200	350		

All samples, except the first, were kept in air 1 day, and the remainder of the time in water.

SAND.

The sand should be sharp, free from clay or earthy materials, and should be preferably pit sand. Sea sand should never be used unless thoroughly washed, as the salt in the sand causes efflorescence, and the cementing material does not adhere well to the rounded grains. Pulverized brick, cinders, furnace slag, etc. are sometimes used as substitutes for sand with good results. The addition of a small quantity of brick dust to ordinary lime-and-sand mortar seems to give it the property of setting under water, and also prevents disintegration when the mortar is exposed to the elements.

MORTAR.

In mixing lime mortar, a bed of sand is first made in a mortar box, and the lime is distributed as evenly as possible over it, both lime and sand being previously measured. The lime should be slaked by pouring on from $1\frac{1}{2}$ to 2 times as much water, and covered with a layer of sand, or preferably, a tarpaulin, to retain the vapor given off. Sufficient water should be used at the start; if more must be added later, it chills the hot lime and makes it lumpy. Too much water makes the paste thin, weak, and slow in drying. Additional sand is then added, if necessary, until the mortar contains the proper proportion, which is usually 3 of sand to 1 of lime, although 2-to-1 is much better. The bulk of the mortar will be about $\frac{1}{8}$ greater than that of the dry sand alone, so that 20 cu. ft. or 16 bu. of sand, and 4 cu. ft. or 3.2 bu. of quicklime, will make about $22\frac{1}{2}$ cu. ft. of mortar.

For cement-and-lime mortar, the materials should be well mixed together before water is added, and the mortar should be used before the cement sets.

A good method of mixing cement mortar is as follows: One-half the quantity of sand is first spread over the bottom of the mortar box; next, the cement is spread evenly over the sand; and the remainder of the sand is then put on. The dry materials are thoroughly mixed together, either by hoe or by shovel; water is then added to so much of the mass as is required for immediate use, and this portion is mixed

until it has the uniform consistency of a stiff paste. The quantity of water required depends upon the cement used, but it is better to have an excess than a deficiency. Owing to the rapidity of setting, only small lots should be mixed at a time.

In winter, a small proportion of lime is sometimes mixed with the cement, the heat generated in slaking being supposed to prevent freezing until the cement has set. Salt is often added for the same purpose, the quantity being about 1 lb. of salt to 18 gal. of water, an additional ounce being added for each degree of temperature below 32° F. Salt is objectionable, however, as it causes efflorescence.

CONCRETE.

Concrete should be made by spreading the *aggregate* evenly over a layer of cement mortar (made as described under *Mortar*) in a box or on a platform, and mixing the materials thoroughly. The aggregate is usually broken stone, not over a specified size; but gravel, broken brick, etc., may be substituted. Whichever is used should be free from dirt, and be well sprinkled before mixing. The pieces should be of different sizes, so that the smaller pieces will fit in the spaces between the larger.

The voids in broken stone are one-half the bulk, which space, in good work, is practically just filled by the mortar; hence, in estimating on concrete, it is necessary to figure about as much broken stone as there are to be cubic yards of concrete. The quantity of sand will be about one-half cubic yard per yard of stone—when gravel is not also used; while the cement will vary according to proportions required. See table on page 170 giving proportions of cement and sand per cubic yard of mortar.

Probably the best proportion for a strong concrete is 1 part of cement, 2 parts of sand, and 4 or 5 parts of broken stone, these quantities being sufficient to fill all the voids.

A very good concrete may be made by using the following quantities of materials, which when mixed will make 1 cu. yd.: 2 bbl. of Rosendale cement, .5 cu. yd. of sand, and

.9 cu. yd. of broken stone. The mortar alone amounts to .55 cu. yd.

A concrete nearly as strong and considerably cheaper is made of 1 bbl. of Rosendale cement, 2 bbl. of sand, .5 cu. yd. of gravel, and .9 cu. yd. of stone. These when mixed will make 1 cu. yd. The mortar amounts to .28 cu. yd.

In laying, concrete should not be dumped from a considerable height, as the thoroughness of the mixture would be destroyed. It should be spread in layers of, say, 8 in. in thickness, and tamped enough to compact the mass well, the surface of each layer being left rough, to form a better bond with the succeeding one.

The strength of concrete increases considerably with age. For example, a Portland cement concrete 1 month old will crush under a load of about 15 tons per sq. ft., while if it is a year old, it will sustain about 100 tons per sq. ft. These figures, under favorable conditions, may be nearly doubled. Natural cement concretes, with various proportions of materials and of ages from 6 months to 4 years, showed crushing strengths of from 70 to 100 tons per sq. ft.

QUANTITIES OF MATERIALS.

Proportion of Mortar in Masonry.

Kind of Masonry.	Per Cent. of Mortar.	
	Minimum.	Maximum.
Brickwork, coarse, $\frac{1}{2}''$ to $\frac{5}{8}''$ joints	35	40
Brickwork, ordinary, $\frac{1}{4}''$ to $\frac{3}{8}''$ joints	25	30
Brickwork, pressed, $\frac{1}{8}''$ joints	10	15
Ashlar, courses 12″ to 20″ high, joints $\frac{3}{8}''$ to $\frac{1}{2}''$	7	8
Ashlar, courses 20″ to 32″ high, joints $\frac{1}{4}''$ to $\frac{3}{8}''$	5	6
Rubble, coarse, not dressed	33	40
Rubble, roughly dressed	25	30
Rubble, well dressed, coursed	15	20
Concrete, clean stone, without gravel or screenings	50	55

Quantities of Materials Per Cubic Yard of Cement Mortar.

Proportions.		Materials.		
		Barrels Cement (Packed).		
Cement.	Sand.	Portland or Eastern Rosendale.	Western Rosendale.	Sand. Cu. Yd.
1	0	7.1	6.4	.0
1	1	4.2	3.7	.6
1	2	2.8	2.6	.8
1	3	2.0	1.8	.9
1	4	1.7	1.5	.95
1	5	1.3	1.1	.97
1	6	1.2	1.0	.98

If brickwork is figured by the thousand brick, the quantities of cement and sand obtained by aid of these tables should be multiplied by either $2\frac{1}{2}$, 2, or $1\frac{2}{3}$, according to whether the brickwork is coarse, ordinary, or pressed. The last given figures are the number of cubic yards which 1,000 standard size brick will lay.

As a perch is $\frac{11}{12}$ of a cubic yard, if stonework is thus estimated, the figures in the tables may be used for perch measurement by deducting $\frac{1}{12}$ from the final results.

Example.—How many barrels of Eastern Rosendale cement and cubic yards of sand will be required for laying 100 cu. yd. of rubble masonry in 1-to-3 cement mortar? By the first table, it is seen that the minimum percentage of mortar in coarse rubble is 33; hence, for each cubic yard of masonry $\frac{1}{3}$ cu. yd. of mortar is required. According to the second table, a 1-to-3 mortar requires, per cubic yard, 2 bbl. of cement and .9 cu. yd. of sand; or 1 cu. yd. of rubble requires $\frac{2}{3}$ bbl. of cement and .3 cu. yd. of sand; and for 100 cu. yd. the quantities are 67 bbl. of cement and 30 cu. yd. of sand.

While founded on actual work, the above tables are not intended to furnish more than fairly close approximations, as there are so many uncertainties about mortar and masonry that very accurate estimates cannot be made.

FOOTINGS AND FOUNDATIONS.

Before beginning a structure, the character of the soil should be investigated. For ordinary work, this can be done by boring—using a 2″ auger—at short intervals, around the site. The auger will bring up samples sufficient to determine the character of the soil. This is a useful precaution, but can be dispensed with for the usual run of buildings, the bearing power being judged by experience of loads in adjacent structures, or by examinations of near-by excavations.

Soils may be classed as rock, ordinary soil, and made ground. A level bed of rock makes the best possible foundation; sand and gravel rank next; clay is safe for moderate loads if kept dry; quicksand should be removed if possible; and soft, marshy ground should be piled, or the footings spread enough to reduce the pressure to safe limits. Made ground, usually formed of garbage, waste earth, etc., should not be built on for important structures, without tests as to its bearing power. For small buildings, however, good made ground is safe to build on. Table XI, page 74, gives the loads which different kinds of soils will carry.

If water is encountered in excavating foundations, careful provision must be made for its removal by means of suitable drains. The ground water level should be considered also. Thus a building may have a good foundation on wet ground, until the water is drained off, by excavation of deep trenches in the street, which causes settlement in the foundation. The frost line, or depth to which ground becomes frozen, must be taken into account, and foundations must be started below it; otherwise they may be cracked and heaved out of place. This depth varies from 3 ft. to 6 ft., according to the severity of the climate.

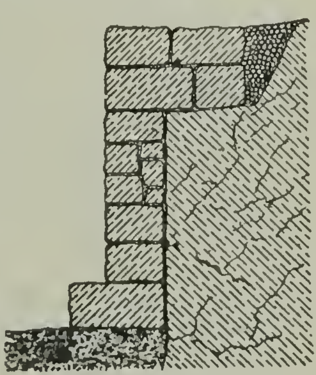


FIG. 1.

Foundations should not be laid on a sloping bed, owing to the liability of slipping. Nor should the walls be built partly on rock and partly on earth, as shown in Fig. 1, for the weight causes the

earth to settle, and the wall, being carried by the rock only, would be unstable; or water, flowing between the rock and masonry, and freezing, might force out the thin wall. When a level bed cannot be otherwise obtained, concrete may be advantageously used for this purpose. If the natural surface is rough, the better will concrete adhere to it. In fact, concrete should be used much more than it is for foundation work. For buildings of moderate weight, erected on soft, clayey soils, the bearing power of the latter may often be considerably improved by spreading layers of sand, gravel, or broken stone, and pounding it into the soil. Or, the soil may be compacted by driving short piles, say 6 ft. long and 6 in. in diameter, as close together as necessary; from 2 to 4 ft. apart is generally close enough. The results will be better if the piles are drawn out and the holes filled with sand, well compacted. Thus the soil is consolidated, and the sand, acting as so many small arches, transmits the load to the sides of the hole, as well as to the bottom.

PROPORTIONING FOOTINGS.

Footings should be designed for the load they are to carry, with the object of producing a *uniform* settlement in all parts of the building. They evidently should not be as wide under an opening as under a solid wall, and when the openings

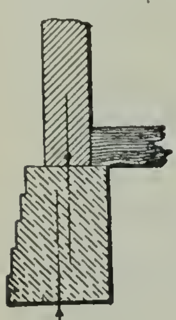
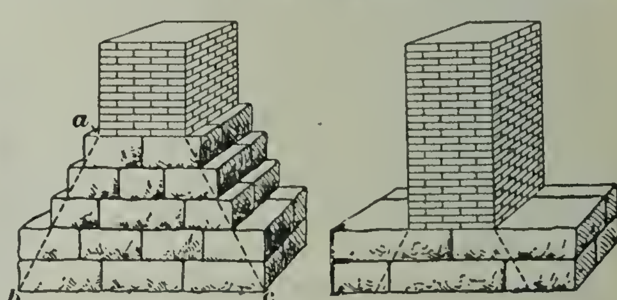


FIG. 2.



(*a*) (*b*)

FIG. 3.

form a considerable proportion of the wall area, that part of the footings under them should be omitted, the weight being transmitted by arches or beams to the footings under the

sides of the openings. This caution is very important, as a majority of cracks in masonry are probably due to continuous footings where little or none are needed. If one portion of the foundation, as, for example, that under a tower, carries much more weight than another part, its width should be proportionately increased. In designing footings, the center of the wall should be placed vertically over, or, preferably, a little inside the center of the base, as sketched in Fig. 2; then the walls will be slightly tilted inwards, but will be kept in place by the floor joists, etc. Where there are interior piers, these should have a somewhat greater load per square foot—that is, less area per ton of load—than the walls, so that the latter will be pressed together, thus preventing cracks; also, as the piers usually support iron columns, to allow for the compression in the brickwork joints, the iron being practically incompressible.

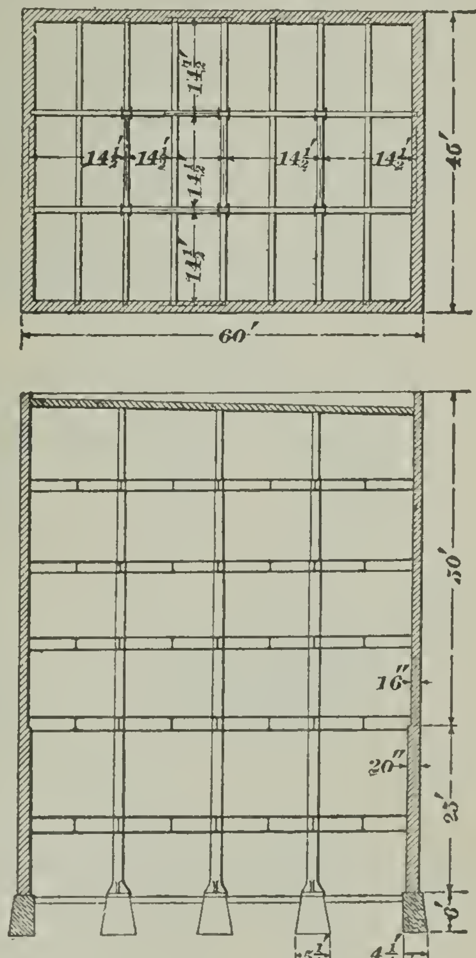


FIG. 4.

Footing courses should be battered or stepped up, making the angle *a b c* in Fig. 3 (*a*), about 60°. The load then becomes well distributed over the base. If the footings are laid as shown at (*b*), the projections are liable to break off at the edges of the wall, and the load will be unevenly carried by the soil.

To show the method of proportioning footings (and of figuring loads in structures), the area of the footings for a 45′ × 60′ brick warehouse, shown in Fig. 4, having five stories and basement, a tar-and-gravel roof, tile arch floors, and without partitions, will be determined. There are two rows of columns, spaced $14\frac{1}{2}$ ft. apart longitudinally and transversely. The walls of the building are 75 ft. high, 25 ft. being 20 in. thick, and 50 ft., 16 in. thick. As the basement floor rests directly on the ground, its load will not be considered. The floor loads on the first and second stories will be taken at 200 lb. per sq. ft., and on the others at 150 lb.

Assume that brickwork weighs 120 lb. per cu. ft.; the tile floor 80 lb. per sq. ft.; the tar-and-gravel roof 10 lb. per sq. ft.; and the snow load at 12 lb. per sq. ft. Then, for each foot in length of the side walls, the load is:

DEAD LOAD.

Walls—

1 ft. 8 in. × 1 ft. × 25 ft. = 41.7 cu. ft.		
1 ft. 4 in. × 1 ft. × 50 ft. = 66.7 cu. ft.		
108.4 cu. ft. × 120 lb.	=	13,008 lb.
Floors—		
(80 lb. per sq. ft. × 1 ft. × $7\frac{1}{4}$ ft.) × 5	=	2,900 lb
Roof—		
10 lb. per sq. ft. × 1 ft. × $7\frac{1}{4}$ ft.	=	72 lb.

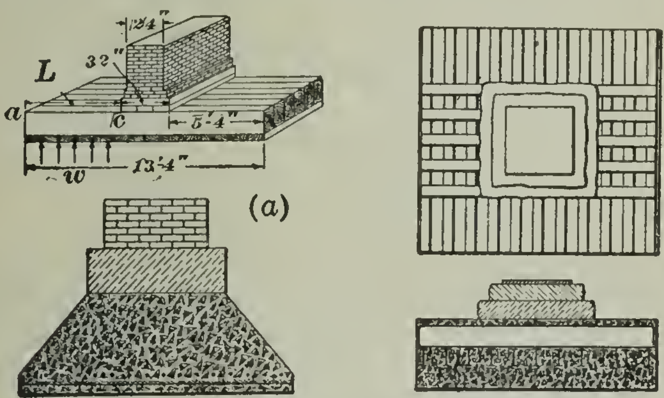
LIVE LOAD.

On Floors—		
(200 lb. per sq. ft. × 1 ft. × $7\frac{1}{4}$ ft.) × 2 = 2,900		
(150 lb. per sq. ft. × 1 ft. × $7\frac{1}{4}$ ft.) × 3 = 3,262		6,162 lb.
Wind, neglected on nearly flat roof		0 lb.
Snow—		
12 lb. per sq. ft. × 1 ft. × $7\frac{1}{4}$ ft.	=	87 lb.
Total dead and live load	=	22,229 lb.

Assume that, upon testing, the soil has been found to be moderately dry clay. By reference to page 74, the average safe load for this soil is found to be 3 tons per sq. ft. Hence, dividing the total load, 22,229 lb., by 6,000 lb., there results $3\frac{2}{3}$ ft. as the approximate width of the footings for the side walls. If the foundation walls are made 6 ft. deep, and bat-

tered 1 in. per foot, the top width will be $2\frac{2}{3}$ ft. Thus far the weight of the foundation wall has not been considered. Having obtained the approximate width of the footing, its weight can now be computed. The average width of the foundation wall is 3 ft. 2 in., and it is 6 ft. deep; the contents will be 19 cu. ft. per foot of length; the walls are good limestone rubble, weighing 150 lb. per cu. ft., so that the total weight will be 2,850 lb. Adding this to 22,229 lb. and dividing by 6,000 lb., the unit load, the final result is about $4\frac{1}{4}$ ft. as the width of the footing. The footings for the end walls and piers may be similarly figured.

Spread Footings.—These are used on compressible soils to bring the load per square foot within the safe bearing power of the soil. They may be made of timber, in wet soils, alter-



(c) FIG. 5. (b)

nate courses being laid transversely; of layers of **I** beams or rails, laid in concrete; or of concrete with several transverse courses of twisted iron rods (a patented method). These are shown at (*a*), (*b*), and (*c*), Fig. 5. In the first two cases, it is necessary to figure the safe length of the projecting portion.

For example, determine the size of the timber footing, Fig. 5 (*a*), for a wall having a load of 40,000 lb. per ft. in length. The ground is wet and not safe to load over 3,000 lb. per ft.; consequently, the footings must be $13\frac{1}{3}$ ft. wide. The stepped-out foundation is 32 in. wide, making the projection L 5 ft. 4 in. on each side. To find what size timber is required,

consider either side as $a c$, a cantilever beam, 1 ft. wide, uniformly loaded, supported at c, and resisting the upward reaction of the earth w of 3,000 lb. per sq. ft.; for 5 ft. 4 in. it is $L w = 16{,}000$ lb.; call this W. According to Table XXVI, page 113, the bending moment is $M = \frac{W L}{2} = \frac{16{,}000 \times 5.33}{2} = 42{,}667$ ft.-lb.; or 512,000 in.-lb.

The resisting moment (see page 114) $M_1 = Q S$, S being the safe unit fiber stress, and Q the section modulus, which for a rectangular beam is, from Table XII, page 83, $\frac{b\,d^2}{6}$; b is the width and d the depth. Suppose that the timber is spruce and that the safe bending stress is 1,000 lb. per sq. in.; let the beam be 12 in. wide; its depth remains to be determined. Then, $M_1 = \frac{1{,}000 \times 12 \times d^2}{6}$. Since the safe resisting moment should equal the bending moment,

$$M_1 = M, \text{ or } \frac{1{,}000 \times 12 \times d^2}{6} = 512{,}000;$$

whence, $$d = \sqrt{\frac{512{,}000 \times 6}{1{,}000 \times 12}} = \sqrt{256} = 16 \text{ in.}$$

Hence, 12″ × 16″ timbers, set side by side, with cross-layers of planks above and below, shown in Fig. 5 (a), would be used.

The principles are the same when the footing consists of **I** beams, or rails, but other values are used for Q and S, on account of the different cross-sections and material. (See page 118 for rolled-steel beams.) The safe offsets for stone footings may also be figured in the same manner. In general, it is best to make the offset in each course of stonework or brickwork not greater than the depth of the course. For calculation of stone beams, as flagstones, lintels, etc., see page 119.

PILES.

When piles are driven closely to confine puddle in a coffer dam, or for preventing the fall of an earth bank, they are called *sheet* piles, and consist of planking from 2 to 6 in. thick, the bottoms being cut at an angle which forms a driving toe, that tends to keep the pile close up to the

adjacent one. The heads are kept in line by securing longitudinal stringers, or wales, to them by spiking or bolting.

Piles which sustain loads are called *bearing* piles. They may be square or round in section, but are usually round, and are from 9 to 18 in. in diameter at the top. They may be used either with or without the bark. White pine or spruce is suitable where the ground is soft; where it is firmer, Georgia pine may be used to advantage. Where the soil is very compact, hard woods, such as oak, hickory, ash, elm, beech, etc., are used. Piles are usually driven at intervals of from $2\frac{1}{2}$ to 4 ft. between centers, according to the nature of the soil and the weight to be sustained.

The following formula gives the safe load for a pile:

$$W = \frac{2\,w\,h}{k+1},$$

in which W = safe load in pounds;
w = weight of hammer in pounds;
h = fall of hammer in feet;
k = penetration of pile in inches at the last blow (head of pile in good condition, not split or broomed).

This formula gives a factor of safety of 6. Assuming that the fall of the hammer is 30 ft., its weight 2,000 lb., and its penetration at the last blow $\frac{1}{2}$ in., or .5 in., the safe load is

$$\frac{2 \times 2{,}000 \times 30}{.5+1} = \frac{120{,}000}{1.5} = 80{,}000 \text{ lb., or 40 tons.}$$

Where piles are spaced at 3 ft. between centers each way, the foundation area will safely sustain a load of from 3 to 5 tons per sq. ft., and when spaced at $2\frac{1}{2}$ ft. between centers each way, the load may be increased to from 5 to 7 tons per sq. ft.

Where the soil is very hard, it is necessary to shoe the piles with cast or wrought iron, to make them drive more easily. In order to preserve the heads from brooming and splitting, wrought-iron hoops, from $\frac{1}{2}$ to 1 in. thick, and 2 or 3 in. wide, are used.

When driven, the piles are carefully sawed off to the same level, usually below the water-line, and capped by cross-rows of timbers or planking, forming a grillage upon which the

masonry is laid. Sometimes large flat stones are laid directly on several of the piles. This method is good, provided the stones are set so as to bear evenly on the piles, without much pinning up by spalls, which are liable to be crushed. The heads of the piles may also be embedded in concrete for 2 or 3 ft., which makes a very satisfactory foundation.

THICKNESS OF WALLS.

Stone foundation walls should be at least 8 in. thicker than the wall above, for a depth of 12 ft. below grade or curb level; for each additional 10 ft. or part thereof in depth, they should be 4 in. thicker. Thus, if the first-story walls are 12 in., the foundation should be 20 in. thick if 12 ft. deep, and 24 in. thick if over 12 ft. Stone foundations should not be less than 16 in. thick; a thinner wall does not bond well; only small stones can be used, and it cannot be carried to any height. The thickness of foundation walls in all the large cities is controlled by the building laws. Where there are no existing laws, the following table will serve as a guide:

THICKNESS OF FOUNDATION WALLS.

Height of Building.	Dwellings, Hotels, etc.		Warehouses.	
	Brick. Inches.	Stone. Inches.	Brick. Inches.	Stone. Inches.
Two stories	12 or 16	20	16	20
Three stories	16	20	20	24
Four stories	20	24	24	28
Five stories	24	28	24	28
Six stories	24	28	28	32

The table on page 179 is a tabulated summary of the New York Building Law in regard to walls, and may be safely taken as a standard. It applies only to buildings having solid masonry walls, and not to those of skeleton-construction type, in which the walls are carried on the framework.

THICKNESS OF WALLS REQUIRED IN NEW YORK.

Dwellings, Hotels, Schools, Etc.

Height Above Curb. Feet.	*Stone Foundation. Inches.	Outside and Bearing Walls.
Up to 35	20	Basement 12″; 8″ above.
35– 50	20	† All 12″.
50– 60	24	First story, 16″; 12″ above.
60– 75	24	Lower 25′ 16″; 12″ above.
75– 85	28	Lower 20′, 20″; next 40′, 16″, above, 12″.
85–100	32	Lower 35′, 24″; next 35′, 20″; above 16″.
100–115	36	Lower 25′, 28″; next 25′, 24″; next 40′, 20″; above 16″.

‡ *Warehouses, Factories, Etc.*

Height Above Curb. Feet.	*Stone Foundation. Inches.	Outside and Bearing Walls.
Up to 40	20	All 12″.
40– 60	24	Lower 40′, 16″; above, 12″.
60– 75	28	Lower 25′, 20″; above, 16″.
75– 85	32	Lower 25′, 24″; next 35′, 20″; above, 16″.
85–100	36	Lower 25′, 28″; next 25′, 24″; next 25′, 20″; above, 16″.

*If brick is used, width may be 4″ less. For foundations over 10′ deep, thickness must be increased 4″ for each additional 10′ or part thereof.

†Non-bearing partition walls, less than 50′ high, may be 8″.

‡If clear span is over 25′, all bearing walls must be 4″ thicker for each 12½′ over 25′ span.

For heights greater than those given, the lower part must be 4″ thicker for each 25′ or fraction thereof in height, the upper 115′ or 100′, respectively, remaining as given in table.

MASONRY CONSTRUCTION.

NOTES ON STONEWORK.

Stone being the stronger material, a wall should have as much stone and as little mortar as possible. Contact of the stones in bed joints is not advisable, as the shrinkage of the mortar may leave them bearing only on the projecting angles. The thickness of joints in stonework is from $\frac{3}{16}$ to $\frac{1}{2}$ or $\frac{5}{8}$ in., depending on the class of work; but for ordinary ashlar, the usual thickness is about $\frac{1}{4}$ in., and more in rough masonry. Bed joints should be full and square to the face, as if worked slack at the back—to make thin face joints—spalls are likely to break off at the front edges. Good bonding is essential for a strong wall, and the proper placing of headers should be carefully watched. Long pieces of stone should be well supported and bedded to prevent breaking; pieces more than, say, four times the thickness, should not be used. Stone, especially if stratified, should be laid on its natural or quarry bed, as if set vertically, water easily penetrates between the layers, and, freezing, splits off the outer ones. For damp places, stonework (and brickwork) should be laid in cement mortar or lime-and-cement mortar, while in dry positions good lime mortar may be used. In laying stone, the mortar should be kept back about an inch from the face of the wall; otherwise spalls may be broken off, owing to the outside mortar hardening more rapidly than that in the interior, settlement bringing the pressure on the hard layer. This precaution is very important in the case of lug sills, band courses, etc. The joints may be pointed, after the wall is built, with some non-staining mortar.

The value of grouted walls is a much disputed point. A wall grouted with thin lime mortar undoubtedly requires a long time to dry thoroughly, while if the grout is thick, it

does not fill every crevice. With cement grout, however, a wall so filled is very much stronger than one laid with stiff mortar, as has been shown by tests. When using cement grout, the brick or stone should not be wet; they will then absorb the water in the grout, and also some of the cement, thus increasing the adhesion. Grout is usually made of ordinary mortar, thinned to the consistency of cream. If an extra strong wall is required, a 1-to-1 mortar may be used.

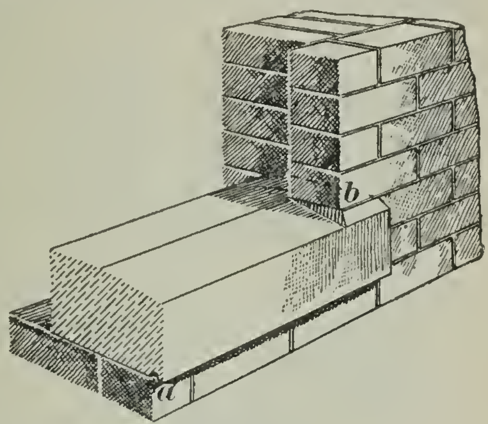


FIG. 6.

Ashlar should be carefully bonded, either by using courses of different thickness, or, if the ashlar is only from 2 to 4 in. thick, by means of wire ties and anchors, such as are shown in Fig. 11. When the courses are from 4 to 8 in. thick, a good bond to the backing may be had by using each thickness in alternate courses. When the backing is brick, the joints in it should be as thin as possible; and if lime mortar is used, some cement should be added, to prevent shrinkage. Very thin ashlar must not be considered in determining the strength of walls, but the backing must be made sufficiently strong, independent of the ashlar.

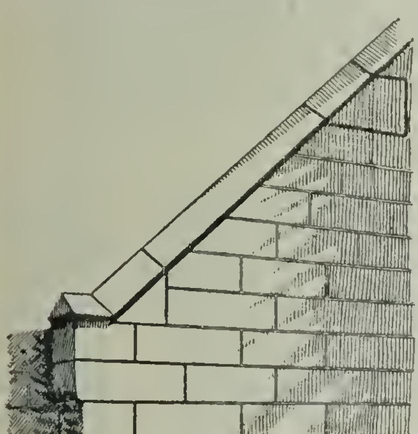


FIG. 7.

All projecting courses, such as cornices, lintels, sills, etc., should be beveled on top, and have a drip cut on the under side, as shown at *a*, Fig. 6, to prevent water from soaking into the joints. Lug sills should only be beveled between the jamb lines, the ends

being cut level, as at *b*, thus keeping out water from the joint between brick and stone, and also forming a more secure bearing for the wall. The top of exposed walls should be covered by coping, in long pieces, and have the vertical joints well filled with good mortar. Gable copings should be anchored very firmly, either by iron dowels or ties, or by bond stones, the latter method being shown in Fig. 7.

CLASSES OF STONE MASONRY.

Rubble Masonry.—This is used for rough work, such as foundations, backing, etc., and although frequently consisting of common field stone, quarried stone should be used where possible, as better bonding and bedding can be secured.

At (*a*), Fig. 8, is shown a common- or random-coursed rubble wall, in which the stones are bonded every three or four feet, as at *a*. The angles are laid with large well-shaped stone, the long sides alternating; in the body of the wall the stones are set irregularly, the interstices in the heart of the wall being filled with spalls and mortar.

At (*b*) is shown *cobweb* rubble, which is used for suburban work. The quoins, or corner stones, are hammer-dressed on top and bottom, but may be rock-faced. All the joints should be hammer-dressed and no spalls should show on the face, while the joints should not be thicker than ½ in. This class of work is more expensive than common rubble.

At (*c*) is shown a rubble wall with brick quoins. In this work all the horizontal joints have hammer-dressed level beds. This makes a good wall and can be built cheaply when the stone used splits readily.

At (*d*) is shown regular-coursed rubble. In this work continuous horizontal joints are run at intervals of 15 to 18 in. in the height, as at *a b c* and *d e f*. No attention need be paid to uniformity of height in the different courses, but the beds should be made as nearly parallel as possible.

Ashlar.—When the outside facing of a wall is of cut stone, it is called ashlar, regardless of the manner in which the stone is finished.

Regular-coursed ashlar, shown at (*e*), Fig. 8, has pieces uniform in height and the courses continuous. Stones about 12 in. high and from 18 to 24 in. long are the cheapest, both as to first cost and in expense of handling. The illustration

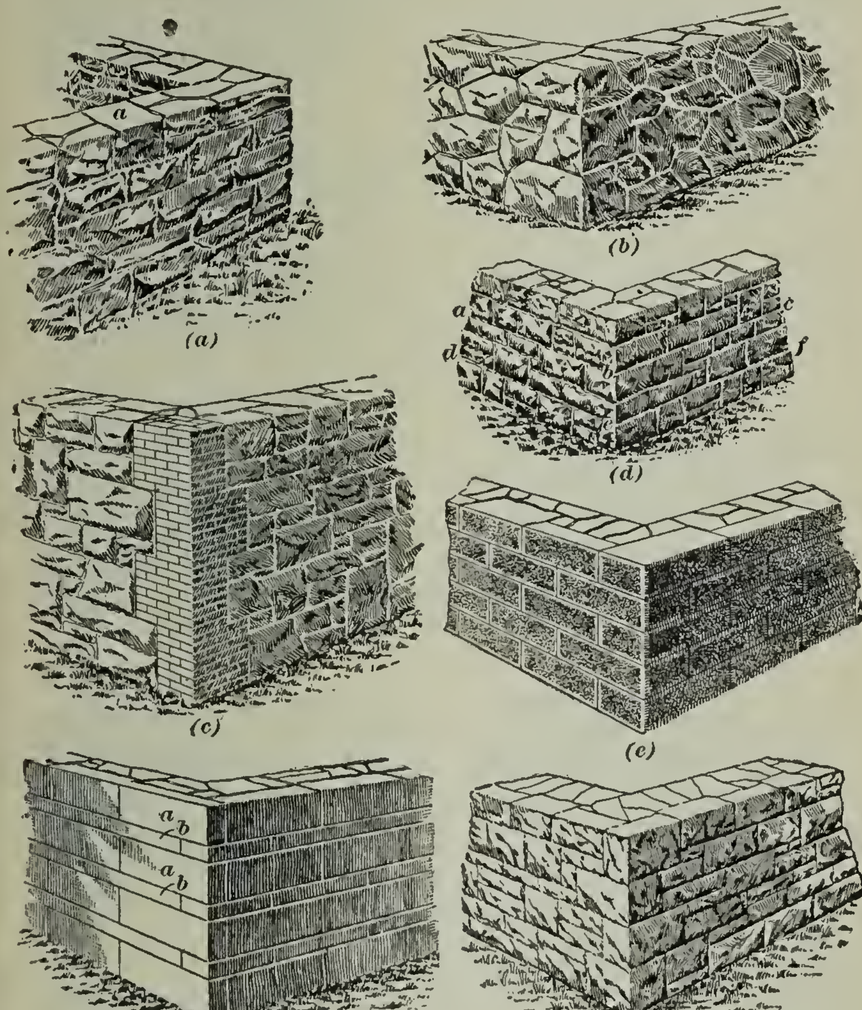


Fig. 8.

shows the stone bush-hammered with tooled draft lines. A good effect is produced by making the courses of two differ ent heights, as shown at (*f*), the courses *a* being from 10 to 18 in. high and composed of "facers," while the courses *b* are

from 5 to 7½ in. high and constitute binding courses. The latter should be at least 4 in. wider than the thickest stones used in the facing courses.

Random, or *broken-range*, ashlar consists of blocks truly squared but of different sizes, forming a broken range or course. As this masonry is in itself irregular, it is well adapted to buildings of irregular plan or of irregular sky line. Random ashlar is finished in various ways. The simplest, though not the least effective, finish is the plain rock face, shown in (*g*). The block must first be cut true and square all around, forming beds and vertical joints, after which straight lines are drawn around the edges, about 2 in. from the face of the block. A wide pitching chisel is then used along these lines, knocking off the surplus material. The smallest stone used should not be less than 4 in. in height, nor the largest greater than 16 in. The bond, or the lap of one stone over another, should be at least 6 in. for the smaller stones and 8 in. for the larger. The length of any block should not be less than 1½, nor more than 4, times its height. The hardest kinds of rock are best suited for masonry of this sort, which is, perhaps, the most common kind of ashlar used in modern building.

STONE FINISHES.

Some of the tools used in making the finer finishes for stonework are shown in Fig. 9. The *crandall* (*a*) consists of a wrought-iron bar, flattened at one end, with a slot, ⅜ in. wide and 3 in. long, in which ten double-headed points, made of ¼″ square steel about 9 in. long, are fastened by means of a key. It is used to finish the surface of sandstone after it has been worked with the tooth-axe or chisel. The *patent hammer* (*b*), made of several thin blades of steel, ground to an edge and held together with bolts, is used for finishing granite or hard limestone. The *bush hammer* (*c*), from 4 to 8 in. long and 2 to 4 in. square, has its ends cut in pyramidal points. This hammer is used for finishing limestone and sandstone after the surface has been made nearly even.

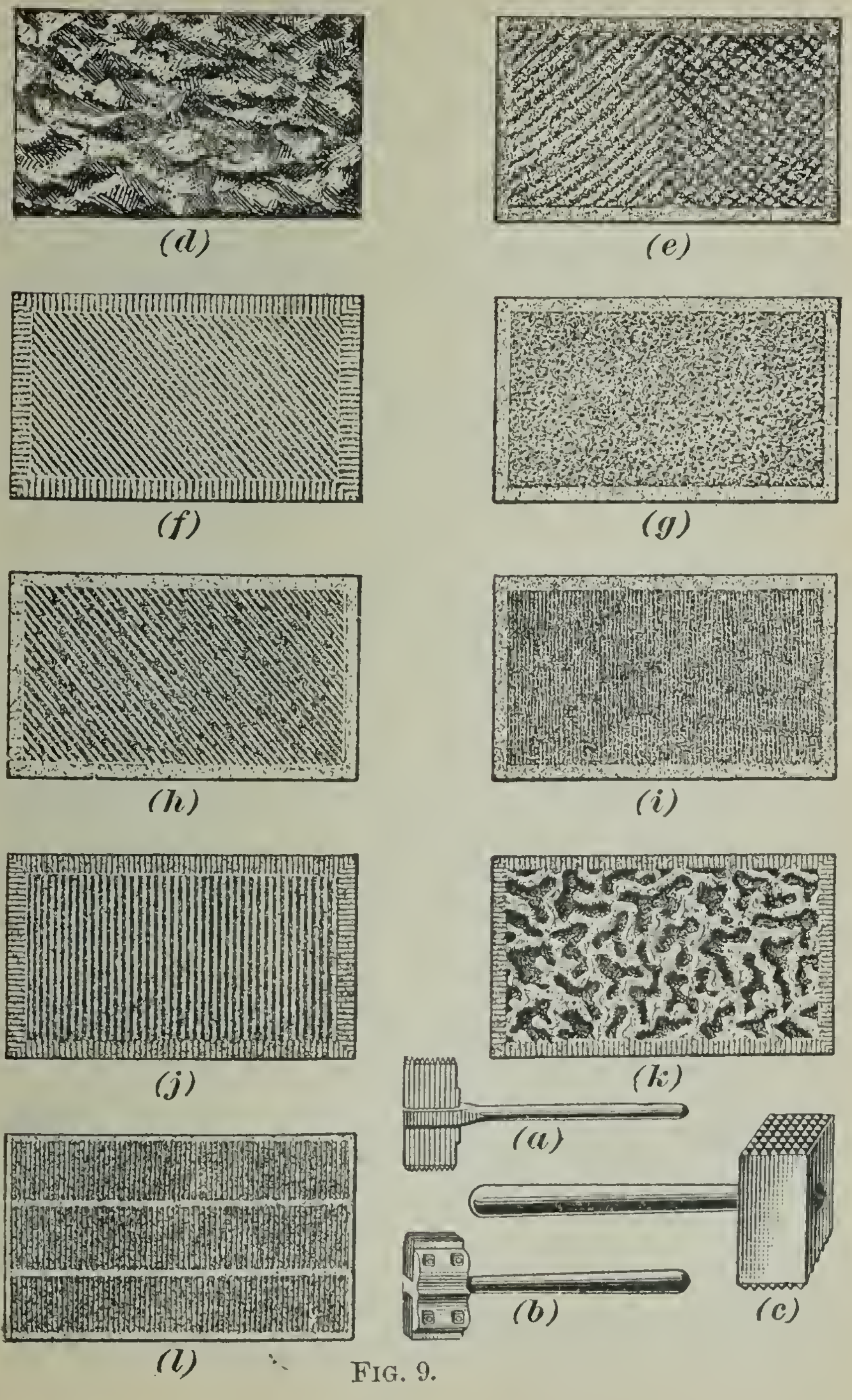


FIG. 9.

At (*d*) is shown the appearance of *rock-faced* or *pitch-faced* work. The face of the stone is left rough, just as it comes from the quarry, and the edges are pitched off to a line. Rock-faced finish is cheaper than any other kind, as but little work is required.

At (*e*) are shown two kinds of *crandalled* work; that on the left shows the appearance when the lines run all one way, while that on the right shows the lines crossing. This finish is very effective for the red Potsdam and Longmeadow sandstones.

At (*f*) is shown *broached* work, in which continuous grooves are formed over the surface.

At (*g*) is shown *bush-hammered* work, which leaves the surface full of points. This finish is very attractive on bluestone, limestone, and sandstones, but should not be used on softer kinds.

At (*h*) is shown *pointed* work; that on the left half of the stone being *rough-pointed*, while the right half is *fine-pointed.* In the rough-pointed work, the point is used at intervals of one inch over the stone, while in the fine-pointed, the point is used at every half inch of the surface.

At (*i*) is shown the *patent-hammered* finish, generally used on granite, bluestone, and limestone. The stone is first dressed to a fairly smooth surface with the point, and then finished with the patent hammer. The fineness of the work is determined by the number of blades in the hammer. For U. S. government work, 10 cuts per inch are generally specified, but 8 cuts per inch is good work.

At (*j*) is illustrated *tooled* work. For this finish, a chisel from 3 to 4½ in. wide is used, and the lines are continued across the width of the stone to the draft lines.

At (*k*) is shown *vermiculated* work, so called from the worm-eaten appearance. Stones so cut are used in quoins and base courses. This dressing is very effective, but expensive.

At (*l*) is shown *droved* work, similar to tooled work, except that the lines are broken, owing to the smaller size of the chisel used. It is less expensive than tooled work.

When a smooth finish is desired, the surface of the stone is *rubbed.* This is best done before the stone becomes seasoned.

BONDS IN BRICKWORK.

In Fig. 10 are shown the three principal bonds in brickwork. In (*a*) is shown English bond, consisting of alternate courses of stretchers and headers. The longitudinal bond is obtained by means of either one-quarter bats, as shown, or preferably by three-quarter bats. This bond is probably the strongest and best one, although not much used. In (*b*) is shown Flemish bond, consisting of alternate headers and stretchers in the same course. The lap is obtained by use of three-quarter bats, with quarter, half, and three-quarter interior closers. In (*c*) is shown the ordinary bond, which consists of 5 or 6 courses of stretchers to each course of headers. This bond is not as strong as the first two named, as there is a continuous vertical joint extending between the header courses.

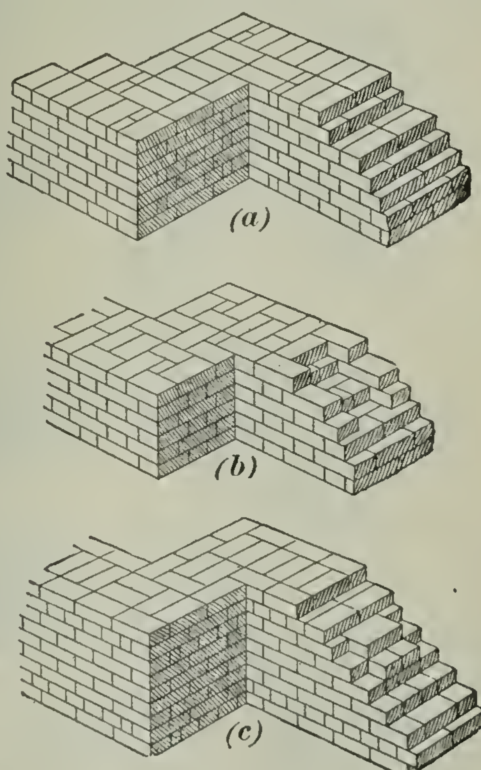


Fig. 10.

From (*a*) to (*i*), Fig. 11, are shown methods of bonding face brick to the backing in both solid and hollow walls; also of bonding terra-cotta furring to walls. At (*j*), (*k*), and (*l*) are shown methods of joining old and new walls; (*j*) shows a vertical groove cut in the old wall to form a sliding joint with the new wall; (*k*), a 2″ × 4″ piece spiked to the old wall for the same purpose; and (*l*), a steel-tie bond (also adapted for bonding face brick).

In Fig. 12 are shown methods of tying face brick to the woodwork in brick-veneered walls by means of steel ties, etc.

MASONRY CONSTRUCTION DURING EXTREMES OF TEMPERATURE.

Extremes of heat or cold are both unfavorable to the union of the building material and the mortar.

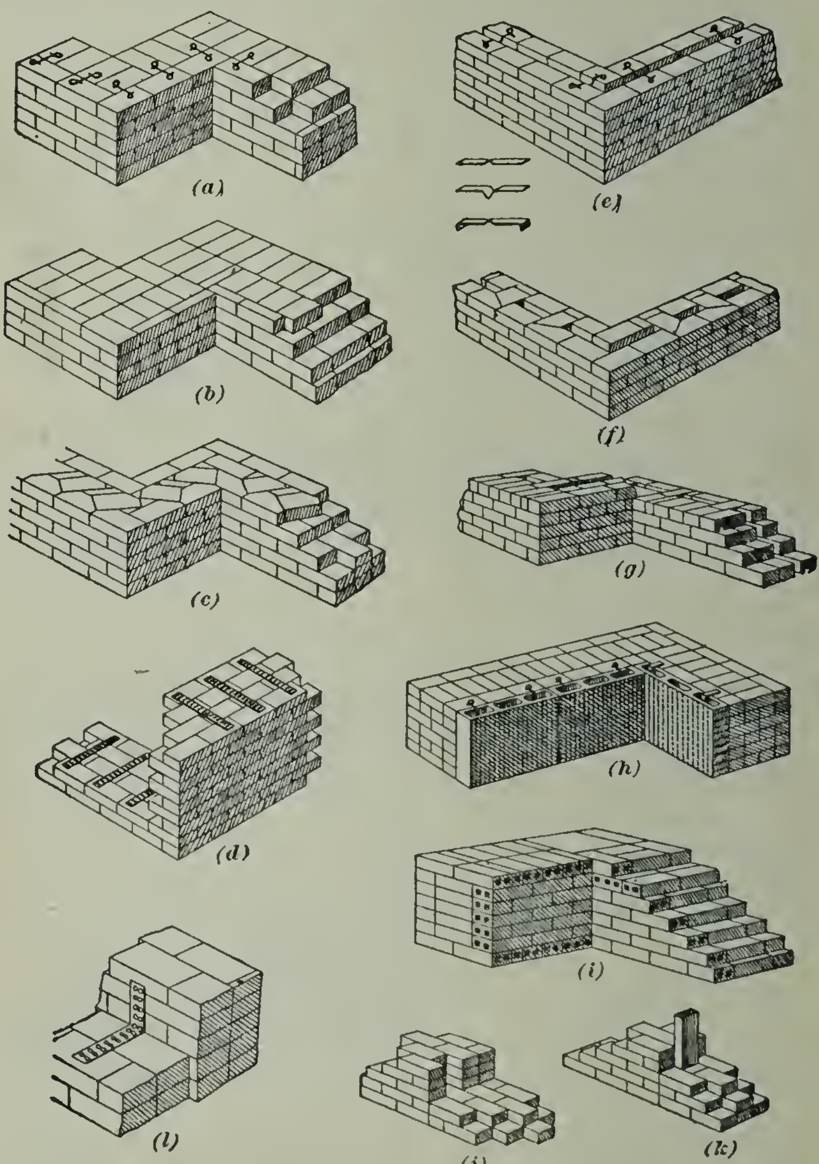
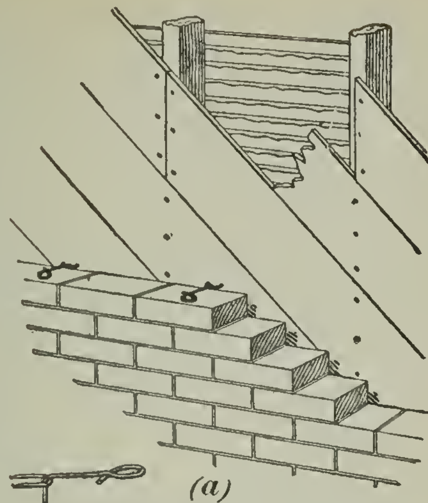
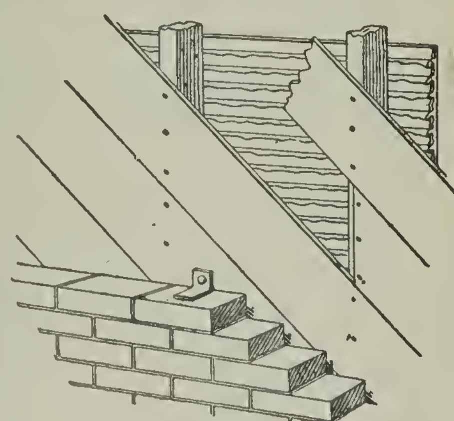


FIG. 11.

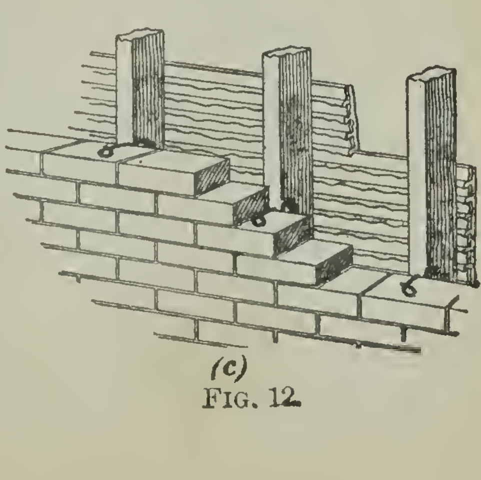
Extreme heat causes quick evaporation of the water in mortar, leaving the mortar in practically the same condition as before mixture. This effect is intensified by the very dry condition of the stone or brick, which readily absorbs moisture from the mortar. In hot weather the surfaces of the brick and stone are covered with dust, which is very detrimental to adhesion, and should be removed before using the material. The mortar, whether lime or cement, should be thinner than usual, and the brick and stone should be well sprinkled before laying. When built, the wall should be frequently sprayed with water, to lower its temperature, and prevent excessive evaporation.



(a)



(b)



(c)

FIG. 12.

In making concrete, the sand and gravel should be well washed, and kept moist by liberal spraying; where practicable, a temporary cover over the work, to keep off the sun's rays, should be provided.

In plastering, similar points require attention; the openings in the build-

ing should be closed, to prevent hot-air currents from extracting moisture too rapidly from the plaster. Where patent plaster is used, the dry lathing should be well moistened before the mortar is applied, and care must be exercised that the coats do not become dry before the subsequent ones are applied. Hard plasters are not injured by frost after they have begun to set, but should be protected from it for the first 36 hours after application.

Extreme cold prevents the setting of mortar by freezing the moisture in it, and also by forming films of ice on the brick or stone. If lime mortar is to be used during freezing weather, rich, newly slaked lime, thoroughly well mixed, gives good results, as it retains much of the heat of slaking. With hydraulic cement the set takes place more rapidly, and, if well begun, frost does not apparently injure the mortar; the particles in combining expel the excess of moisture; a much closer contact is thus secured, and the mortar is denser. Although, in appearance, the work may not have suffered from the action of frost on the cement, many experiments have conclusively shown that cement mortar after freezing loses as much as one-third the tensile strength it possesses when not frozen.

In order to lower the freezing point, a solution containing 2 or 3 per cent. of salt is mixed in the mortar, reducing the temperature of freezing about 5°; that is, until the thermometer registers below, say, 28°, the operations are safe. It has been conclusively proved, however, that the addition of salt to cement is injurious to its strength, as the crystallization of the salt creates a force opposing adhesion, and tends to disintegrate the particles; salt also attracts moisture, thus making the walls constantly wet.

The top of the walls should be kept covered when work is stopped, so that rain may not enter and, freezing, separate the constituent parts of the masonry. Sheets of tarpaulin or roofing felt are most convenient for the purpose. When the temperature has reached the freezing point, it is unsafe to dress-cut unseasoned stone in the open air, as the quarry sap in the stone freezes, and the stone may be fractured during the process of cutting.

WATERPROOFING WALLS.

Damp cellar walls are due either to water soaking through from the outside, or to wet bottoms, from which water rises in the walls by capillary action. The decay of vegetable matter contained in dirty water generates gases injurious to health, so that the prevention of dampness in walls is a point of great importance. Provision must be made to convey the water away from the walls, as well as to make the latter damp-proof. No earth should be placed against the wall, a 12″ or 18″ space next to it being filled with broken stone or gravel, with, if practicable, an open-jointed tile drain laid at the bottom, as shown in Fig. 13. The outside of the walls and footings should be plastered thickly with 1-to-1 cement mortar; or, preferably, with asphalt and coal tar, mixed in the proportion of 9 to 1, and applied, while hot, about $\frac{3}{8}$ in. thick to the dry walls. The asphalt course should also extend through the walls, as shown at the under side of the concrete floor, which should be 3 or 4 in. thick, and laid on a 6″ or 8″ bed of broken stone. In place of concrete, a very durable composition, made of 60 parts of hot asphalt, 10 of coal tar, and 30 of sand, may be used.

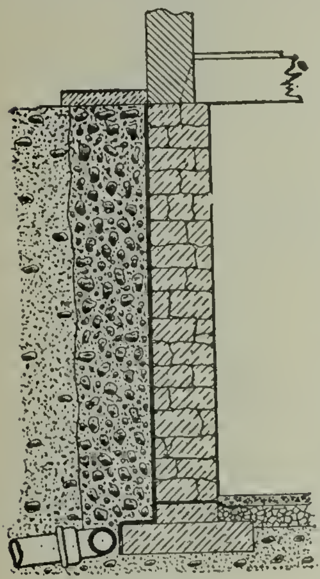


FIG. 13.

The ascent of moisture in walls may be prevented by inserting on the footing course two courses of roofing slate, or very hard brick, laid with broken joints in cement mortar, or a few layers of tarred felt may be used.

Efflorescence.—Efflorescence, or the white coating frequently seen on the outside of stonework and brickwork, is caused by the deposition of soluble matter in the mortar, which, being dissolved in the water used in mixing, is deposited upon the surface of the wall, as the water evaporates. This efflorescence may be removed by washing the walls with a dilution of muriatic acid in 20 parts of water. When clean and dry the

walls may be coated with a preservative; one of the commonest being boiled linseed oil, which, applied in 2 coats, and, when dry, washed over with weak ammonia, will be effectual for 2 or 3 years before needing renewal. Lead and oil paint is sometimes used, but is objectionable, as it changes the color of the masonry, and also flakes off. Cabot's brick preservative is used to waterproof brick and sandstone, and is effectual where the heart of the wall is kept dry.

Sylvester's process, which has proved quite successful, and is simple in preparation and application, consists of two washes, the first being made of Castile soap and water, in the proportion of $\frac{3}{4}$ lb. of soap per gallon of water, and the second of $\frac{1}{8}$ lb. of alum per gallon. The soap wash is applied, boiling hot, with a brush, to the clean and dry walls, and allowed to dry 24 hours before the alum wash—which need not be hot—is put on in the same manner. The coats are applied alternately 2 or 3 times, making the wall practically impervious.

All ordinary cements will cause efflorescence, and when such are used in stonework, the face stones should be set entirely with Vicat, Lafarge, or some other non-staining cement mortar, mixed with sand in the proportion of 1 to 2. If this method be too expensive, the joints of the stonework may be raked out to a depth of 1 in., and pointed with a mortar made with one of these cements. Good lime mortar is often used in setting ashlar, and by some is claimed to be practically as good for the purpose, and considerably cheaper than the cements named.

CHIMNEYS AND FIREPLACES.

Chimneys.—In planning chimneys, the points to be considered are the height, and the number, size, and arrangement of the flues. Attention must also be given to the location in respect to valleys, etc. on the roof. To make the chimney "draw" properly, a separate flue should be provided, extending from each fireplace to the top of the chimney. For ordinary stoves and small furnaces, the flues may be 8 in. × 8 in.; but if the furnace is large, it is better to make the flue 8 in. × 12 in., and the same size should be used, when possible, for fireplaces having large grates. (See *Fireplaces.*) Flues

are sometimes only 4 in. wide; but are then easily choked with soot and difficult to clean, so that a flue should not be less than 8 in. wide. Flues should always be lined with some fireproof material; in fact, the building laws of large cities so require. The lining is usually fireclay, tile, or galvanized-iron pipe. If the pipe used is round, the space between it and the walls of the chimneys may be utilized for ventilation. The outer walls of chimney flues should be 8 in. thick, if flue linings are not used. Whenever it is necessary to change the direction of the flue, the diversion should be effected by long curves, and not by sharp turns, which retard the passage of smoke. Chimneys should extend above the highest point of the building or of those adjoining; otherwise they are likely to smoke. This may be obviated, when the chimney is not carried high enough, by using a hood having two open sides; but as hoods are unsightly, their use should be avoided, when possible. The top of a chimney should be covered by a stone slab, either solid, to prevent the entrance of rain—the smoke passing out through holes at the sides near the top—or with a hole the size of the flue cut in it, preventing disintegration of the exposed mortar joints.

Fireplaces.—The general construction of a fireplace is shown in Fig. 14. The projection in the room is called the chimney breast, and its width *a* is generally 5 ft., which is the standard width for ordinary fireplaces, the return *b* in this case being 17 in. The height of the fireplace opening at *c* is about 30 in. from the finished floor line to the springing line of the arch, the rise of which may be 3 or 4 in. The width of the opening between the rough bricks, as *d*, should be 25 or 26 in., and the depth of the niche *e*, from 12 to 13 in. These measurements may be adjusted to suit special grates and fittings.

The arrangement of the floor framing requires no explanation, other than that the trimmer joists should be kept 2 in. from the brickwork. A temporary wooden center supports the brick trimmer arch during construction. The space above the arch is leveled up with cement concrete, upon which is laid the slate or tile hearth. With this method of constructing a fireplace, it is almost impossible for the woodwork to catch fire.

The opening above the fireplace, or throat, is gradually contracted to the size of the flue lining, as shown at l and m. Several courses of brick are corbeled out from the back, as at n; on the ledge formed is placed a sliding iron damper. A

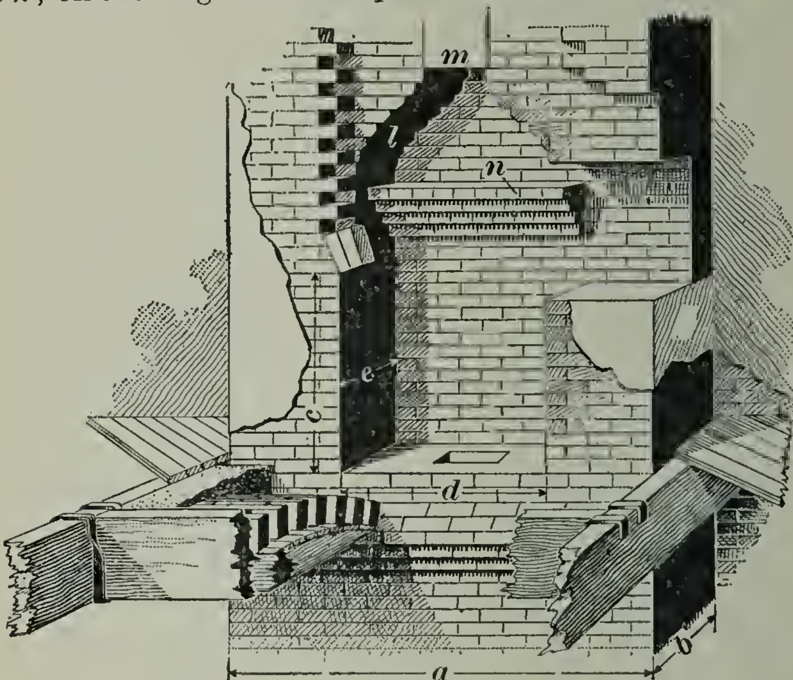


FIG. 14.

preferable form of construction consists in the insertion, just below the throat l, of a tilting damper, which may be operated by a key placed in the front of the fireplace.

A good proportion for flues of fireplaces in which it is intended to burn wood or bituminous coal, is to make the sectional area of the flue $\frac{1}{10}$ that of the fireplace opening, if the flue is rectangular, and $\frac{1}{12}$ if the flue is circular; thus, for a fireplace which is 30 in. wide × 30 in. high, or 900 sq. in. in area, the area of a rectangular flue would be 90 sq. in., which is nearly equivalent to an 8″ × 12″ flue; for a circular flue it would be 75 sq. in., which is equivalent to a 10″ flue. When anthracite coal is to be used in the fireplace grates, the flue area may be made $\frac{1}{15}$ that of the fireplace opening for the rectangular form, and $\frac{1}{18}$ for the circular.

CEMENT WALKS AND FLOORS.

Where the curb is not already in place, stakes should be set to grade and to aline either edge of the walk, the other being obtained by leveling over, taking care to allow an outward pitch on the surface of about $\frac{1}{4}$ in. per ft. Straight-edged strips should be nailed to the inside of each line of stakes, with top edges level with them, to form the mold for the concrete. The ground should be leveled off about 10 in. below the finished grade of the walk, and well settled by ramming, as at *d*, Fig. 15.

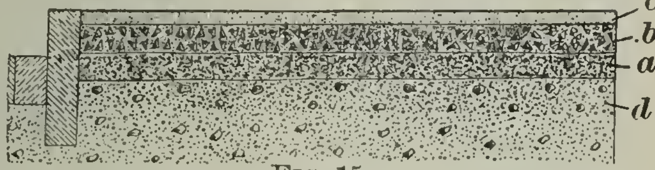


FIG. 15.

A foundation *a*, 5 in. thick should then be laid, of either coarse gravel, stone chips, sand, or cinders, well tamped or rolled. The concrete should have the proportions of 1 part of cement, 2 parts of sand, and 5 or 6 parts of gravel, mixed dry; then a sufficient quantity of water is added to make a stiff mortar. This concrete should be spread in a layer from 3 to 4 in. thick, as at *b*, and should be well tamped. Before it has set, the finishing coat *c* should be laid, and only as much concrete should be laid as can be covered with cement the same day, for if the concrete gets dry on top, the finishing coat will not adhere to it. The top coat should consist of equal parts of the best Portland cement and sand, or clean, finely crushed granite or flint rock, mixed dry, water being then added to give the consistency of plastic mortar. It should be applied with a trowel, to the thickness of 1 in., and be carefully smoothed and leveled flush with the tops of the guides. It is best to mark off the walk into squares, etc., by grooves $\frac{1}{4}$ or $\frac{3}{8}$ in. deep, so that in case it should crack, the fractures will follow the grooves and not disfigure the whole walk. In hot weather, the cement should not be allowed to dry too rapidly, but should be sprinkled occasionally. Usually a walk is ready for use in from 24 to 30 hours after completion, and the forms may then be removed.

The same general methods above described apply to cemented cellar floors.

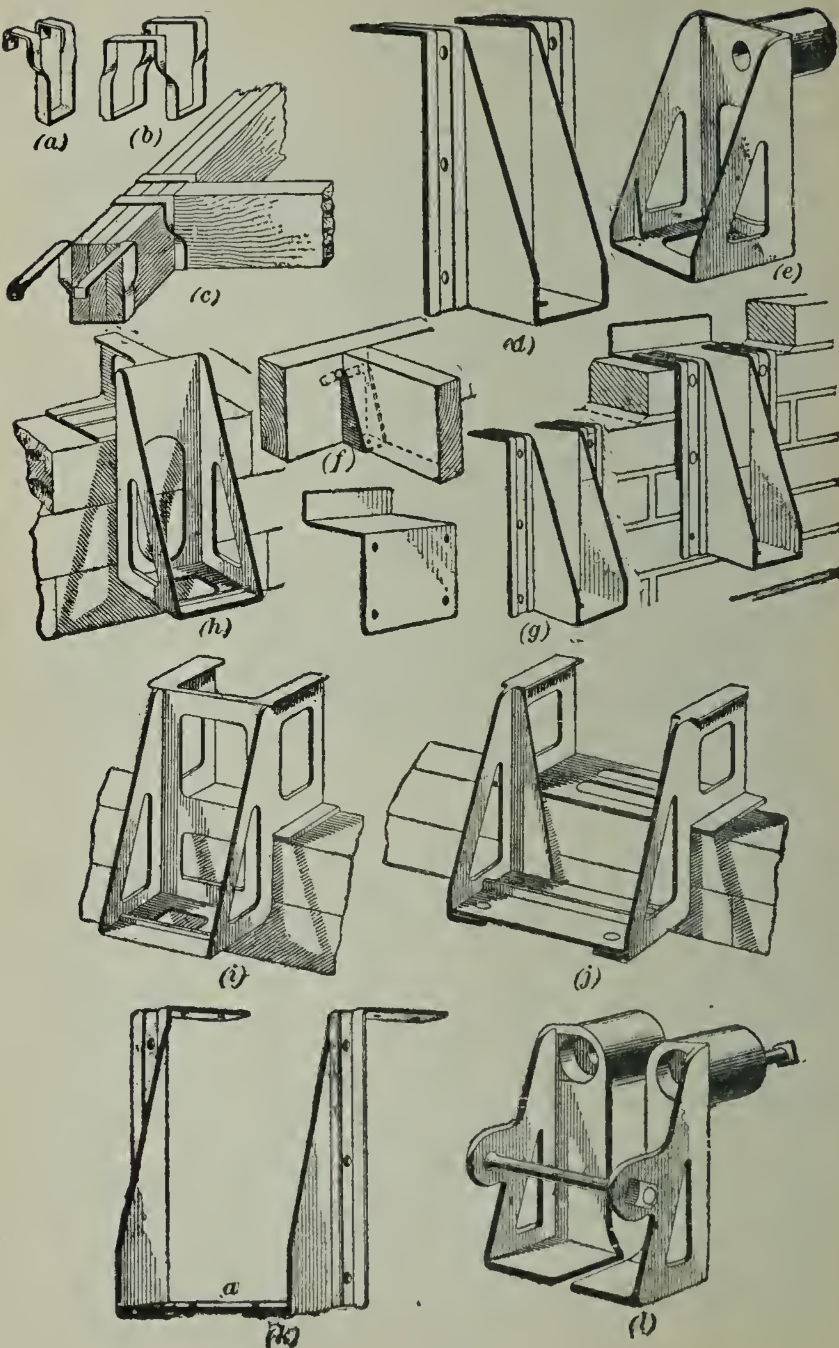


FIG. 16.

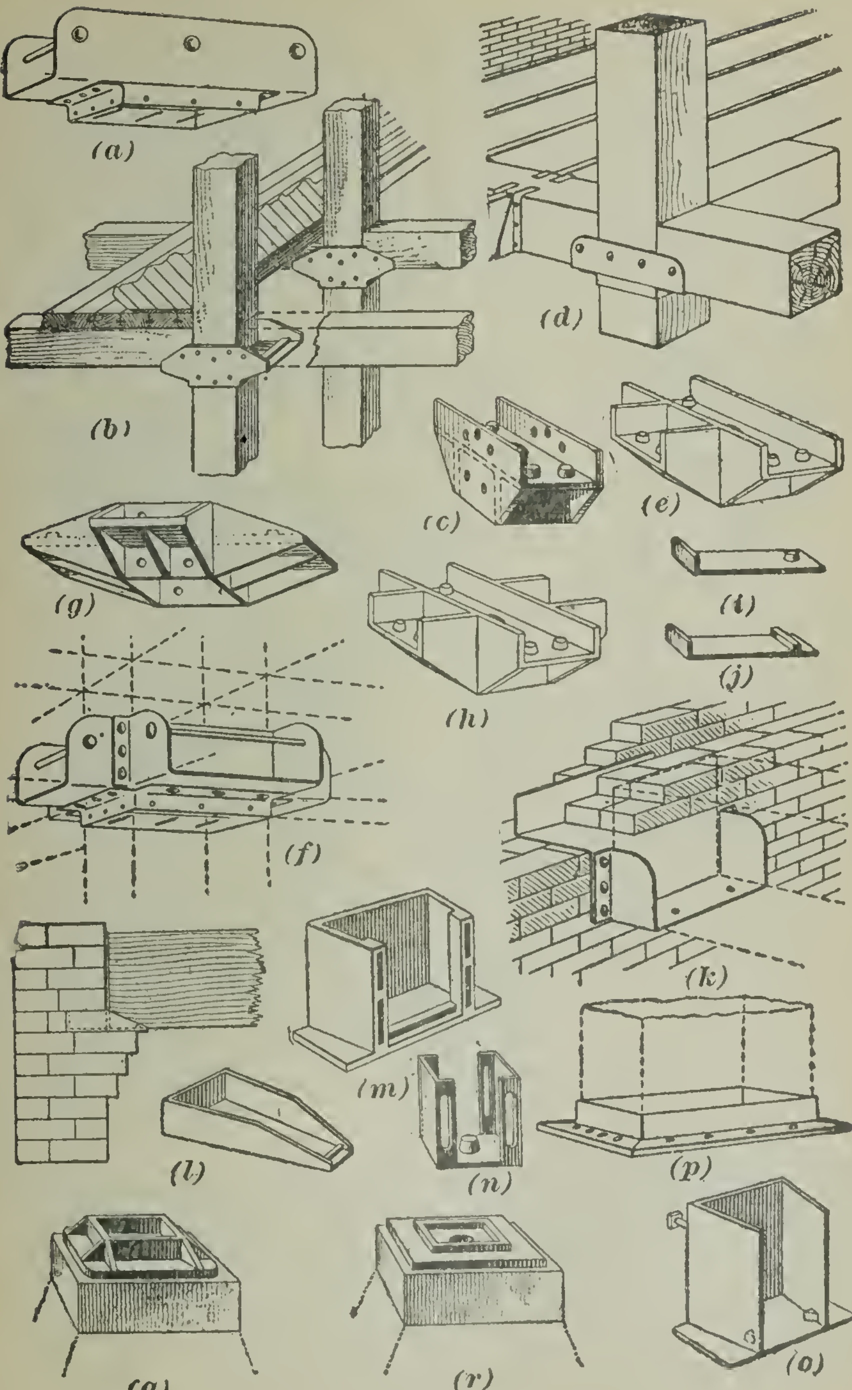


FIG. 17.

HANGERS, CAPS, ANCHORS, ETC.

The use of joist and girder hangers, etc. simplifies greatly the work of framing both for house and mill construction. With these hangers a good bearing and firm support for the joists, girders, etc. may be had, and in case of fire the timbers may give way without injury to the masonry.

At (*a*), (*b*), and (*c*), Fig. 16, are shown the ordinary forms

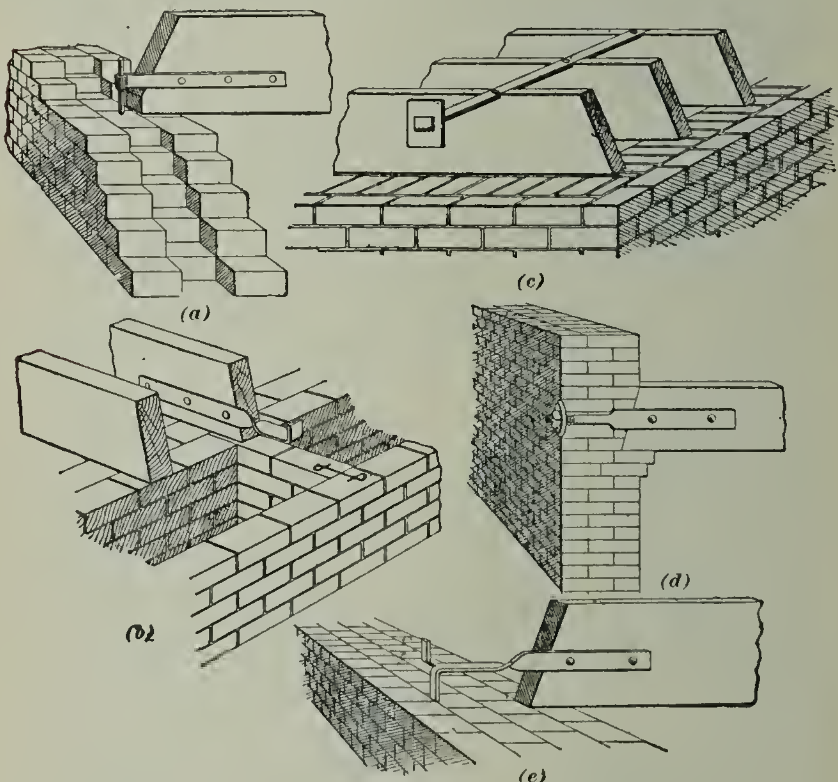


FIG. 18.

of wrought-iron stirrups, or hangers; at (*d*), (*e*), and (*f*) are shown joist hangers for use in frame buildings; at (*g*), (*h*), (*i*), and (*j*) hangers for use in brick walls. At (*k*) is represented a hanger for heavy girders or joists, adjustable to suit several sizes of timber by changing the bearing plate *a*, thus serving the same purpose as that shown at (*l*), which represents a hanger made in right and left parts, and fastened

together by a bolt. Of the hangers shown, (*d*), (*g*), (*k*) are the Van Dorn; (*c*), (*h*), (*i*), (*j*), (*l*), the Duplex; and (*f*), the Goetz, types.

At (*a*), (*b*), and (*c*), Fig. 17, are represented 2-member post caps; one is steel and the others are cast iron. At (*d*) and (*e*) are shown 3-member post caps; at (*f*), (*g*), and (*h*), one steel and two cast-iron 4-member post caps. At (*i*) and (*j*) are shown two cast-iron wall-bearing plates; at (*k*), a steel wall-plate hanger; at (*l*), a cast-iron box anchor for use over a ledged wall; at (*m*), (*n*), and (*o*), cast-iron bar anchors, the latter for I beams. At (*p*) is shown a steel base plate, and at (*q*) and (*r*), two forms of cast-iron base plates. The caps, etc., shown at (*a*), (*d*), (*f*), (*k*), and (*p*), are the Van Dorn; and those at (*b*), (*c*), (*e*), (*g*), (*h*), (*l*), (*m*), (*n*), and (*o*), the Goetz styles.

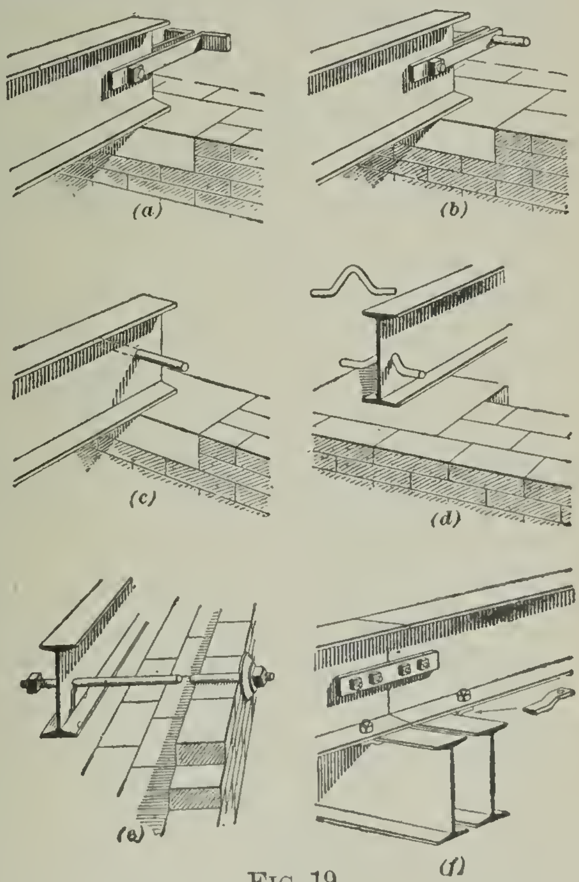


FIG. 19.

In Fig. 18 are shown the common forms of anchors for tying wood floor joists to masonry. They are made of wrought bar iron about $\frac{1}{4}$ in. $\times$ 2 in., and about 2 ft. long. Where the anchor passes through the wall, as at (*d*), a cast-iron washer, or plate, holds the anchor in place.

In Fig. 19 are shown several forms of ties for anchoring I

beams, channels, etc.; (*a*), (*b*), (*c*), and (*d*) represent ordinary wall anchors; (*e*) is a tie-rod anchor running through the wall, and (*f*) shows the upper I beams connected by a *fish-plate* and secured to the girder by *clips*.

When wall boxes or hangers are not used, templets, or bearing stones, should be placed under the ends of beams and girders, to distribute the weight evenly on the wall. They should be of tough stone, having a thickness of about ⅓ the least surface dimension, but not less than 4 in. It is well to place flat stones above the joists, etc., so that any shrinkage in the latter will not affect the wall. The building laws of some cities provide that joists shall be supported on corbels, at least 4 in. wide. This is a good construction, but a cornice is required to conceal the corbel.

ARCHES.

The general forms of arches are semicircular, segmental, pointed, elliptical, etc., the name being determined by the curve of the *intrados*, or inner curve of the arch. The outer curve is termed the *extrados*. The *soffit* is the concave surface of the arch. *Voussoirs* or *ringstones* are the pieces composing the arch, the center or highest stone being termed the *keystone* or *keyblock*. The first courses at each side are called *springers*, except in the case of segmental arches, in which they are termed *skewbacks*. The voussoirs between the skewbacks or springing stones and the keystone collectively form the *flanks* or *haunches*, and the *spandrels* are those portions of the wall above the haunches and below a horizontal line through the crown of the extrados. See Fig. 20.

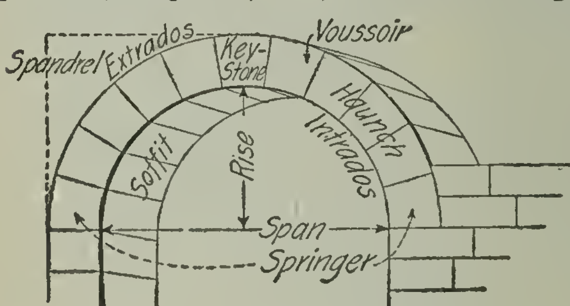


FIG. 20.

The *span* is the horizontal distance between jambs, and

the perpendicular distance from the springing line to the highest part, or *crown*, of the soffit is the *rise*.

The joints of circular and segmental arches radiate from a single center. In arches having two or more centers, the joints in each arc of the curve radiate from their respective centers. The joints of elliptic arches are found thus: Draw lines from each of the several points (spaced off on the intrados or extrados) to the foci, as shown at (n), Fig. 21; bisect the angles thus formed, and the bisecting lines will give the direction of the joints. The joints in flat arches are drawn from the vertex of an equilateral triangle having the springing line as a base.

EXAMPLES.—At (a), Fig. 21, is shown a semicircular arch, of which $a\,b$ is the springing line and $c\,d$ the rise.

At (b) is shown a segmental arch; the center a is taken on the line $a\,b$, which bisects the span $c\,d$. The radius of this arch equals approximately the square of the span divided by eight times the rise. For exact formula, see Sector, page 37.

At (c) is shown a *Moorish*, or *horseshoe*, arch, the springing line $a\,b$ being below the center from which the curve is struck, making a sweep of about 230 degrees. A similar form is the pointed Moorish arch, differing from (c) only above the line $c\,d$, above which it takes the form of a two-centered or pointed arch. These two arches are called *stilted* arches, from the fact that the center is raised above the springing line.

Another example of stilted arch is shown at (d), in which the arch centers are on the line $a\,b$, and the springing line $c\,d$ is below it.

At (e) is shown a *flat* arch built of wedge-shaped voussoirs, together serving as a lintel; the joints radiate from a center at the vertex of an equilateral triangle of which the span is one side.

At (f) is represented a brick *relieving* arch $a\,b\,c$, intended to carry the weight of the wall above; by this construction the lintel d merely sustains its own weight and that of the small brick segment e.

At (g), (h), and (i) are shown methods for drawing *two-centered*, *pointed*, or *Gothic* arches. At (g) is represented an *equilateral* arch, or one in which the radius a of each curve is

the same length as the springing line $b\,c$. At (h) is shown an arch in which the centers are taken inside the jamb lines,

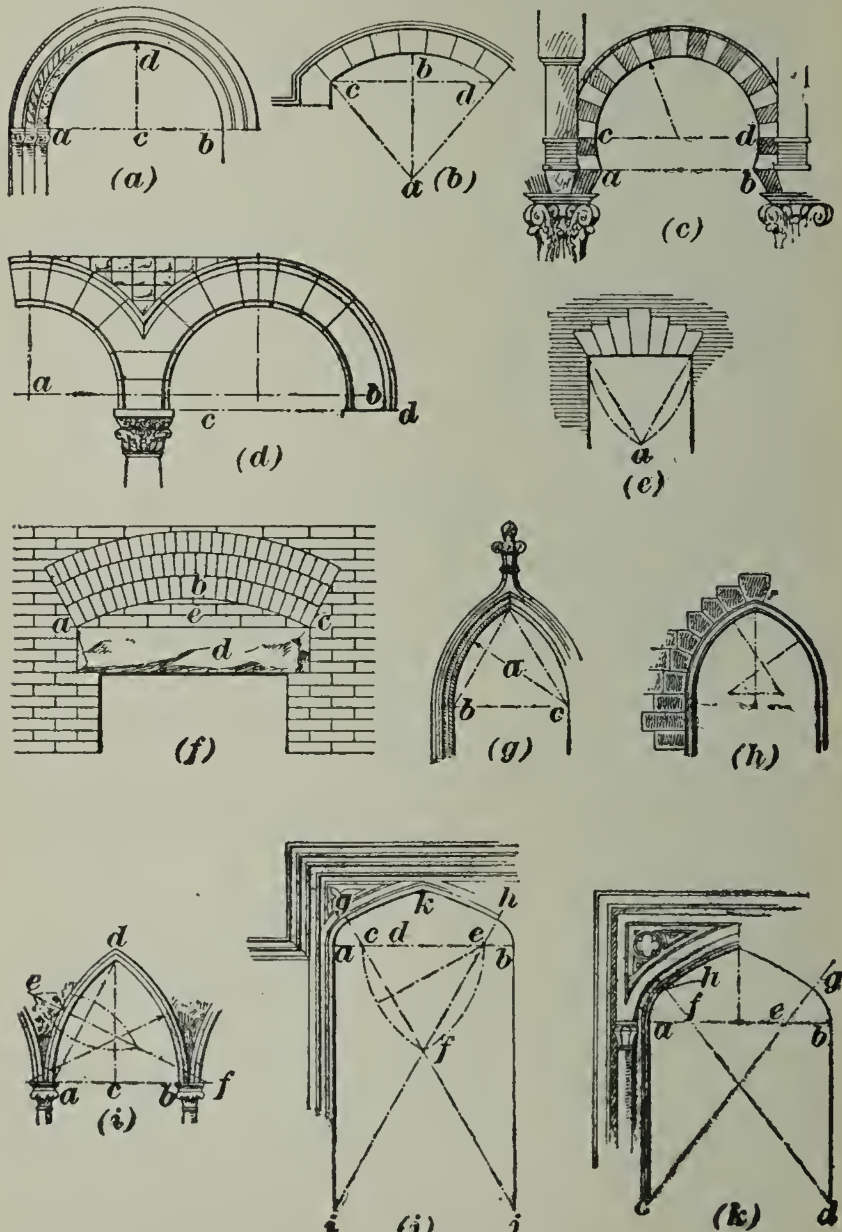
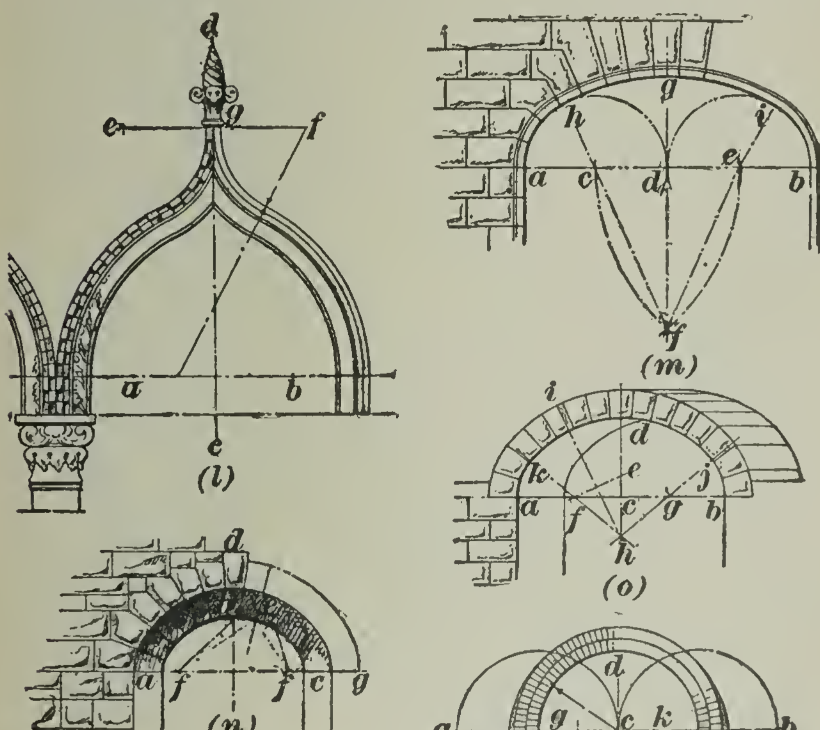


FIG. 21. (a.)

thus flattening the arch; in this example, the radius is equal to ¾ of the span. At (*i*) is shown a pointed arch having the span *a b*, and the height *c d*, which is greater than the span. To find the centers, proceed as follows: Draw the line *a d*, and bisect it by *e f*, which cuts the springing line at *f*, on



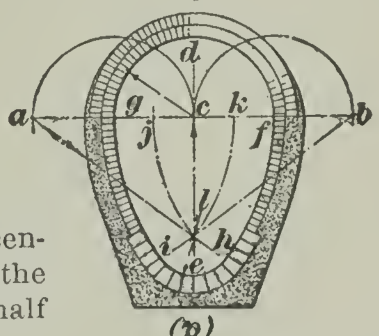


FIG. 21. (*b*.)

a b produced. Then, with *f* as center and a radius *f a*, one side of the arch may be drawn, the other half being similarly found.

At (*j*) and (*k*) are shown examples of *four-centered Gothic*, commonly called *Tudor*, arches. At (*j*) is represented an arch in which the given span *a b* is divided into six equal parts, as at *c*, *d*, *e*, etc. To find the centers for the longer radii, with *c* and *e* as centers, and a radius *c e*, describe arcs intersecting at *f*; draw *f c* and *f e*, and produce these

lines to g, h, i, and j; the last two points will be the required centers. With c and e as centers, and a radius $c\,a$, describe arcs $a\,g$ and $b\,h$; with i and j as centers, and a radius $i\,h$, describe the arcs $h\,k$ and $g\,k$.

At (k) is shown an arch of similar construction, but the span $a\,b$ is divided into four equal parts. The distances $a\,c$ and $b\,d$ are each made equal to $a\,b$; lines are then drawn from c and d through e and f, and produced to g and h; the arcs are then struck in a manner similar to that shown at (j).

At (l) is represented an *ogee* arch, which is stilted one part in seven of the total height. The span is divided into six equal parts, and the centers for the lower arcs are taken at a and b, at each side of the center line $c\,d$; the arcs are tangent on the outer line of the molded architrave, the position of e and f being determined by the width of the neck at g.

At (m) is shown a three-centered arch having the span $a\,b$ given. To lay out this arch, divide $a\,b$ into four equal parts, as at $c\,d\,e$; from a and b as centers, with a radius $a\,e$, describe the arcs $e f$ and $c f$, intersecting on the center line $f g$. From c and e as centers, with a radius $c\,a$, describe the arcs $a\,h$ and $b\,i$; and from f as a center, with the radius $f\,h$, describe the arc $h\,g\,i$, completing the figure.

At (o) is shown a three-centered skew arch, which closely approaches an elliptic curve in form. To construct the arch, having given the required span $a\,b$ and the height $c\,d$, proceed as follows: Take any point e on $c\,d$, and make $a\,f$ and $g\,b$ equal to $e\,d$. Draw $f\,e$, and bisect this line by the line $h\,i$, cutting the center line $d\,c$ at h. Draw $h\,f\,k$ and $h\,g\,j$; with f and g as centers, draw the arcs $a\,k$ and $b\,j$; and with h as a center, draw the arc $k\,d\,j$.

At (p) is represented a form of arch used for egg-shaped sewers. To lay out the curves, draw the springing line $a\,b$ and the center line $d\,e$; from f and g as centers, with a radius $g\,c$, describe arcs cutting the springing line in a and b; with these points as centers, and a radius $a\,f$, describe the arcs $f\,h$ and $g\,i$. Divide the span $g\,f$ into four equal parts by points j, c, and k, and from the points a and b as centers, with a radius $a\,k$, describe arcs intersecting the center line $d\,e$ at the point l;

now, with l as the center, and a radius $l\,h$, describe the arc $h\,e\,i$; draw the upper curve $g\,d\,f$, which is a semicircular arc struck from the common center c, thus completing the figure.

To construct a *rampant* arch (such as is used for carrying a flight of stone steps), as shown in Fig. 22, the base line $a\,b$ and the angle of inclination being given, draw $a\,b$ to the required length, and at a lay off the angle of inclination; draw the line $a\,c$; bisect it, and at the points a, b, and c erect the lines $a\,d$, $b\,e$, and $f\,g\,h$, each perpendicular to $a\,b$. Now, through h—a point on the under side of the arch determined by the thickness required for the step backing and voussoirs—draw a line $d\,e$ parallel to $a\,c$, completing the rhomboid $a\,d\,e\,c$. Divide the line $a\,c$ into any number of equal parts, and divide $a\,d$ and $c\,e$ into one-half as many equal parts. From h draw lines to the points on $a\,d$ and $c\,e$ just found; make $g\,f$ equal to $g\,h$, and from f draw lines through the points on the line $a\,c$, producing them to intersect those first drawn, as at j, etc. These points then will be on the required curve, which may be readily traced through them. To locate the axes and foci of the ellipse, erect $c\,k$ perpendicular to $a\,c$ at c, and make it equal in length to $g\,h$. With g as a center, and a radius $g\,k$, describe an arc intersecting $e\,c$ at l; a line drawn from l through the center g will give $i\,m$ as the major axis; and $n\,o$, perpendicular to it at g, will be the minor axis. Taking the distance $g\,m$ as the radius, and with n as the center, describe arcs cutting the major axis at v and p; these points will be the foci of the ellipse, and, after marking the thickness of the joints on the intrados, the joint lines may be drawn as explained for (n), Fig. 21.

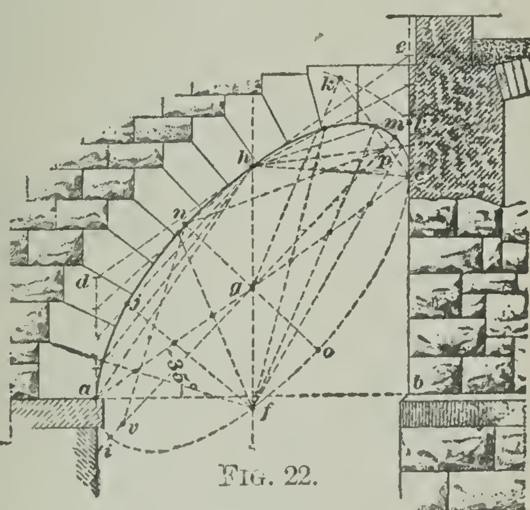


FIG. 22.

N

RETAINING WALLS.

A retaining wall is a wall built to rebut the pressure of earth, either wet or dry. In designing such a wall it is necessary to ascertain the character of the material to be retained. If the latter is rock, the wall evidently need not be as thick as if the material were wet clay, and would be merely a face wall.

Any granular material, when unconfined, spreads out to its natural slope, termed technically the *angle of repose*, which varies with the material and also with the quantity of moisture in it. The slope usually taken in engineering work, as being safe for nearly all kinds of earth, is $1\frac{1}{2}$ ft. horizontal to 1 ft. vertical, corresponding to an angle of 33° 42′. The pressure, then, which a retaining wall sustains, is evidently the weight of the prism of earth included between the back face of the wall ab, Fig. 23, and the plane bc, inclined to the horizontal at the angle of repose of the material—the earth having a level top surface. The amount and direction of this pressure are indeterminate, and so many varying factors enter into the problem that no attempt will be made to explain the theory of retaining walls, and only a few practical points will be touched on respecting their design.

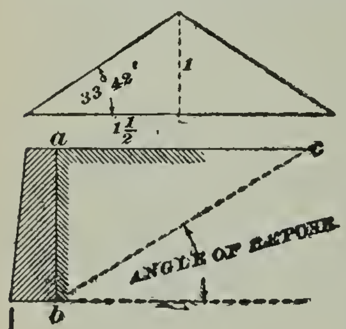


FIG. 23.

There is considerable diversity of practice in the proportioning of retaining walls. Most authorities, however, agree that the base should be from .3 to .5 of the height, the latter ratio being the greatest required under any but the most unusual conditions.

The following proportions represent very safe—but not excessive—construction: In Fig. 24, let $ah = 1$; then $gk = .4$; $ab = \frac{1}{6}$; $gh = \frac{1}{12}$; cd, ef, etc. = from 9 to 12 in. each, the distance ik being divided up so as to make steps of about these widths. For example, let $ah = 16$ ft.; then $gk = 16 \times .4 = 6.4$ ft., say 6 ft. 6 in.; $gh = \frac{1}{12}$ of 16 ft. = 1 ft. 4 in.; $ab = \frac{1}{6}$ of 16 ft. = 2 ft. 8 in.; cd, etc. = $(gk - gi) \div 3 = 10$ in.

The preceding proportions are not intended to apply in their entirety to small walls less than about 6 ft. high; in such cases steps are usually unnecessary, and the top width should not be less than 18 in., so that the wall may be sufficiently thick to withstand the action of frost on the backing. A wall designed as above indicated will be amply strong to retain a considerable surcharge, or bank, of earth sloping back above the top of the wall. Area walls that are supported at short intervals by cross-walls, beams, etc. do not need to be as thick as retaining walls which have no such bracing.

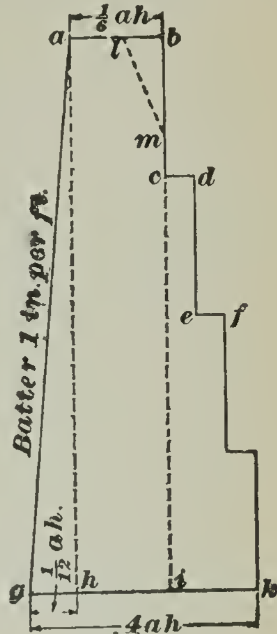


FIG. 24.

The masonry courses, while usually laid horizontally, should preferably be laid sloping towards the embankment, to lessen the liability of slipping, and should be started below the frost line. The stones should be as large as possible, bonding and breaking joints both longitudinally and transversely. If built of brick, the bond should be the same as stone, with broken joints, wherever possible, to make the wall a homogeneous mass. The back should be left rough, to increase the friction between the wall and the backing, and, as the work progresses, it should be coated thickly with hot coal tar, or other waterproof material, as a precaution against water soaking in. Above the frost level, on the upper surface of the embankment, the back of the wall is sometimes battered sharply up to the coping, as at lm, Fig. 24, to guard against displacement by the action of frost upon the backing. To prevent the accumulation of water at the back of the wall, porous drain tiles should be laid at proper levels along the back of the wall, to collect all surface and rift water, and discharge the same through small openings, called *weepers*, left in the wall for that purpose. The natural drainage of the soil never should be dammed up by a wall.

CARPENTRY AND JOINERY.

WOODS USED IN BUILDING.

White, or Northern, pine is a light, soft, straight-grained wood, and is used in building principally as a finishing material where a good but inexpensive job is required. Its power of holding glue renders it valuable to the joiner.

Georgia pine, also known as *hard pitch*, or *long-leafed, pine*, has a dense dark color, and well-marked grain, on account of which it is sometimes used as a finishing material. The wood is heavy, hard, strong, and, under proper conditions, very durable, but decays rapidly in damp places. On account of its resinous nature it does not take paint well. Georgia pine is often confused with *Carolina, yellow*, or *Southern pine*, which is greatly inferior to it.

Loblolly pine, sometimes called *Texas pine*, has a close resemblance to Georgia pine, but is of coarser grain, softer in fiber, and grows more sap-wood. It is largely used in the Southern states for framework and interior finish.

Oregon pine, sometimes called *Washington fir*, while really belonging to the spruce family, so closely resembles pine that it is so called. While nearly as strong as Georgia pine, it is much lighter in weight, and more easily worked. Owing to the long lengths in which it can be obtained it is in demand for flagstaffs and long framing.

Black spruce, growing in the Southern states and Canada, is light in weight, reddish in color, and though easy to work, is very tough in fiber. It is largely used for submerged cribs and piles, as it not only preserves well under water, but also resists the destructive action of parasitic crustacea.

White spruce, scarcely distinguishable from black, is largely used throughout the Eastern states for all classes of lathing, framing, and flooring.

Norway spruce has a tough, straight grain which makes it an excellent material for masts of ships, etc. Under the name of *white deal* it fills the same place in European woodworking shops as white pine does in America.

Red spruce, growing in the Northeastern portion of the United States and in Canada, is similar to black spruce.

Hemlock is like spruce in appearance, but much inferior in quality, is brittle, splits easily, and liable to be shaky. It is only used as a cheap, rough framing timber.

White cedar, a soft, light, fine-grained, and very durable wood, lacking strength and toughness, is much used for boat-building, cigar-box manufacture, shingles, and tanks.

Red cedar, a smaller tree than white cedar, similar to it in texture but more compact and durable, is of a reddish-brown color, and possesses a strong, pungent odor, which repels moths and other insects, making it extremely valuable as shelving for closets, and linings for chests and trunks.

Cypress, a wood very similar to cedar, growing in the Southern part of both Europe and the United States, is one of the most durable woods, and well adapted for outside or inside work. Special care must be taken in seasoning it, as it tends to sliver and become shaky if forced in the drying.

Redwood, the name given to one of the species of giant trees of California, grows to a height of from 200 to 300 ft., its trunk being bare and branchless for one-third of its height. The color is a dull red, and the wood, resembling pine, is used in the West the same as pine is in the East. As an interior finish it is capable of taking a high polish, and its color improves with age.

White oak is the hardest of the American oaks, and grows in abundance throughout the eastern half of the United States. The wood, heavy, hard, cross-grained, strong, and of a light yellowish-brown color, is used where strength and durability is required, as in cooperage and carriage making.

Red oak is darker and redder, coarser, more brittle, and of a more porous texture than white oak.

English oak, though similar to American oaks, is superior to them for such structural purposes as ship building and house framing.

Oak is especially prized as a material for cabinetwork, when the log is quarter-sawed. In first-class work, it is usually cut into veneers $\frac{3}{16}$ in. thick, which are laid on cores of white pine or chestnut. The silver grain and the

high polish that the wood is capable of receiving make it one of the most beautiful used in joinery.

Hickory is the hardest and toughest of American woods, and, owing to the difficulty in working it, is very little used as a building material. Hickory is also attacked by boring insects. This wood possesses great flexibility, and hence is valuable for carriages, sleighs, and implements requiring bent-wood details.

Ash, the wood of a large tree growing in the colder portions of the United States, is heavy, hard, and very elastic. Its grain is coarse, and very much like bastard-sawed oak in appearance. Ash is sometimes used for cabinetwork, but its tendency to become decayed and brittle renders it unfit for structural work. The *white* ash is exceedingly tough, and is largely used for interior trim. It closely resembles white oak, and when properly filled can be brought to a high polish. *Black* ash has a brown, cedar-like appearance.

Locust is one of the largest forest trees in the United States, and furnishes a wood that is as hard as white oak. It is composed of very wide annual layers, in which the vessels are few but very large and are arranged in rows, giving the wood a peculiar striped grain. Its principal use is in exposed places where great durability is required. As its hardness increases with age, it is used for turned ornaments and occasionally in cabinetwork.

Black walnut is heavy, hard, porous, and of a purplish color, marked by a beautiful wavy grain. Strong, durable, and not subject to the attacks of insects, it is used generally for small cabinetwork, gun stocks, and interior decoration. The knotted roots of the tree furnish material with a curly grain, called *burl*, which is cut up into veneers.

Cherry.—The wood of the wild cherry is moderately heavy, hard, very durable, and has a close, fine grain. It is susceptible of a high polish, and is much used for fine interior trim and cabinetwork. Cherry stained black to imitate ebony cannot be detected, except by scraping the polished surface. It is largely used for piano cases, furniture, etc.

Birch strongly resembles cherry in texture, and in some species in color also. *Black* or *cherry* birch furnishes the best

lumber, but is not as durable, and is more affected by atmospheric influences.

Maple is a light-colored, fine-grained, strong, and heavy wood. The medullary rays are small and distinct, giving a silver grain to the quarter-cut lumber. It is used for flooring and interior trim, but for fine work it is used as veneers. *Curly* maple is maple in which the waviness of the grain is similar to that obtained from the roots of the walnut tree. *Bird's-eye* maple is produced in old trees by the circular inflection of the fibers. Though both the curly maple and the bird's-eye are practically distorted fibers, and reduce the strength of the wood, they are highly prized in the cabinet-maker's art.

Chestnut is comparatively soft, close-grained, and, though very brittle, is exceedingly durable when exposed to the weather, and has recently come into use for interior finish. It is not as well suited for sills as locust.

Butternut is of a light color and possesses a strongly marked grain. The lumber can be secured only in short lengths, and though soft and easily worked it will not split easily; it resists moisture, and remains unaffected by heat until the wood begins to char. It is not suitable for framing material, but is used in cabinet work on account of its taking a very high polish.

Beech is hard and tough, of a close, uniform texture, which renders it desirable for tool handles and plane stocks. It is used but slightly in building, owing to its tendency to rot, but may be used where constantly submerged.

Poplar, or **whitewood,** a lumber of the tulip tree, is a large straight forest tree, abundant in the United States. It is light, soft, very brittle, and shrinks excessively in drying. In color it varies from white to pale yellow. The cheapness and ease of working poplar cause it to be largely used for the cheaper grades of carpentry and joinery work, but it warps and twists exceedingly in even slight atmospheric changes.

Buttonwood, also called *sycamore,* is the wood of a tree generally known as the *plane tree.* It is heavy, hard, of a light-brown color, and very brittle. The grain is fine, close, and susceptible of a high polish. It is very hard to work, liable

to decay, and has a strong tendency to warp and twist under variations of temperature. On this account it is best used for veneered work.

Apple and **pear** trees furnish wood to be used for tool handles, plane stocks, and small turned work. Neither is much used in building. Pear wood is sometimes used for carved panels, on account of its yielding so easily to edge tools.

Boxwood is close-grained, yellow in color, and on account of its lack of shrinking and warping tendencies, very desirable for small carved and turned work. It is particularly useful in wood engraving.

Basswood is the name given to the *American linden* tree. In general appearance it strongly resembles pine, but is much more flexible. It has a great tendency to warp, and will shrink both across and parallel to the grain. It is much used for curved panels.

Mahogany is a native tree of the West Indies and Central America. The color, grain, and hardness of the wood vary considerably according to its age and locality of growth. It is used for the highest grades of joiner work. The straight-grained varieties do not warp or shrink materially with atmospheric changes, while the cross-grained varieties warp and twist to a remarkable extent, and can, therefore, be used to advantage only when veneered upon some more reliable wood. The soft and inferior grades from Honduras and Mexico are called *baywood* to distinguish them from the rich deep-red San Domingo or Spanish mahogany. *Prima Vera* or *white* mahogany is of a creamy color, very much like the baywood in texture, and makes a beautiful finish for fine work.

Rosewood is a heavy, hard, and brittle wood, from several trees native to the tropical countries. It has a beautiful grain, alternating in dark brown and red stripings, which when well polished makes the surface one of the handsomest products of the vegetable world. As a veneer, it is applied to all kinds of cabinet, furniture, and joinery work where richness and durability are required, regardless of expense.

Ebony, a dark, almost jet-black wood, native to the East Indies and parts of Africa, is heavy, strong, and exceedingly

hard, with an almost solid annual growth. It takes a high polish, and is used in cabinetwork ; its veneers are also applied to interior work.

Lignum vitæ is an exceedingly heavy, hard, and dark-colored wood. It is very resinous, difficult to split, and soapy to the touch ; it is used mostly for small turned articles, tool handles, and pulley wheels.

Sweet- or **red-gum,** a tree of large growth, is very plentiful in the Southern and Western States. It is soft in texture, but strong and tough, and strongly resembles light-colored walnut. It presents a very handsome appearance when selected and well finished, but has a tendency to warp and shrink, which makes it unreliable, unless used in veneered work. It is largely used for fine interior trim, and cabinet-work.

RELATIVE HARDNESS OF AMERICAN WOODS.

If the hardness of shell-bark hickory is assumed to be 100, other woods will compare with it as follows :

Shell-bark hickory	100	Yellow oak	60
Pignut hickory	96	White elm	58
White oak	84	Hard maple	56
White ash	77	Red cedar	56
Dogwood	75	Wild cherry	55
Scrub oak	73	Yellow pine	54
White hazel	72	Chestnut	52
Red oak	69	Yellow poplar	51
White beach	65	White birch	43
Black walnut	65	Butternut	43
Black birch	62	White pine	30

QUALITIES OF TIMBER.

The best timber is obtained from mature trees, the fibers of which have become compact and firm, both by the drying up of the sap and by the compressive action of the bark. There is a great difference both in appearance and strength between the heart-wood, or *duramen*, and the sap-wood, or *alburnum ;* in the former, the fibers are firm and dense, and possess a deep color ; in the latter, they are open, porous, and filled with sap, and are usually of a pale color. The heart-

wood is much stronger, and less liable to decay and to the attacks of insects, than sap-wood.

The *medullary rays* consist of vertical layers or sheets, radiating from the center, and connecting the pith with the bark, as shown at *i* and *j*, Fig. 1. They are not, however, continuous, but are broken by the interweaving of the fibers. Those rays extending from the pith to the bark are called *primary* rays; those extending through only a portion of the stem are called *secondary* rays. The medullary rays are prominent in oak, beech, and sycamore, but are not so well defined in birch, chestnut, and maple. It is the presence of these medullary rays, sometimes called *silver grain*, that gives so much beauty to quartered oak.

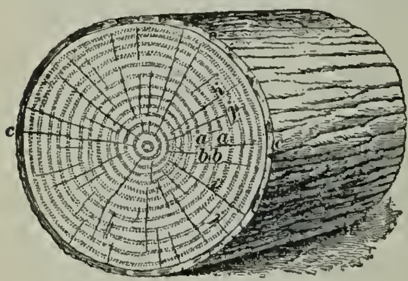


FIG. 1.

Fig. 1 represents a section of an oak or ash tree of 13 years' growth, the coarse texture formed of the large sap vessels being shown at *a*, the closer texture at *b*, the bark at *c*, the primary medullary rays at *i*, and the secondary ones at *j*.

Selecting the Stock.—In good lumber for building purposes, the heart-wood should be sound and mature, the sap-wood, or layers next the bark, being entirely removed. The wood should appear uniform in texture, straight in fiber, be free from large or loose knots, flaws, shakes, or any kind of blemish. When the rings are close and narrow, they denote a slowness of growth, and are usually signs of strength. When freshly cut, the wood should smell sweet; a disagreeable smell is a sign of decay. The surface, when sawed, should not appear woolly, but be firm and bright, and it should not be clammy and choke the saw. When planed, the wood should have a silky appearance; the shavings should come off like ribbons and stand twisting around the fingers. When the wood appears dull and chalky, and the shavings are brittle and friable, it is not first-class stock. Good lumber should be uniform in color; when blotchy or discolored it signifies a diseased condition.

Imperfections.—There are various defects in timber which may be caused either by the nature of the soil in which it grew or by accidents due to storms, etc.

Heart-shakes are cracks or partings of the fibers, radiating from the center of the tree. They are common in nearly all classes of timber, and are caused by the shrinkage of the inner layers incidental to loss of vitality; the cracks are wider towards the heart.

Star-shakes are cracks radiating from the center, but differ from heart-shakes in that they are wider towards the bark; they are caused by the rapid drying of young timber while it is full of sap.

Cup-shakes are curved splits which separate the layers, and are caused by severe wind storms.

Rind-galls are curved swellings, caused generally by resinous layers forming over a wound where a branch has been broken off.

Foxiness is a yellow or red coloring, signifying the early stages of decay.

Dry-rot is a fungus growth, and can be discovered by a black-and-blue tinge; the end wood is crumbly and crisp. Timber thus affected is of no permanent value, as the rot continues until the fiber becomes powder.

Twisted fibers are caused by the twisting tendency of winds blowing generally in one direction; such timber possesses little strength, owing to the oblique direction of the fibers.

Knots are either stubs of branches or the gnarly growth formed where the branches are lopped off. Knots may be small and sound, in which condition they are not objectionable, or they may be large and loose; if large, the strength of the timber is very much reduced, and, if loose or dark in color, they will ultimately fall out, loose knots being the stubs of dead branches.

QUARTER AND BASTARD SAWING.

The term *quarter sawed* signifies that the log is cut into quarters before being reduced to boards, while the term *bastard sawed* denotes that all the saw cuts are parallel to the squared side of the log. In genuine quarter sawing (also

called rift sawing) the cuts should be as nearly as possible at right angles with the circles of growth, or parallel with the medullary rays *a*, as shown in Fig. 2; while in bastard sawing, the cuts are nearly parallel with the circles of growth and expose the edges of the medullary rays *a* and the full-

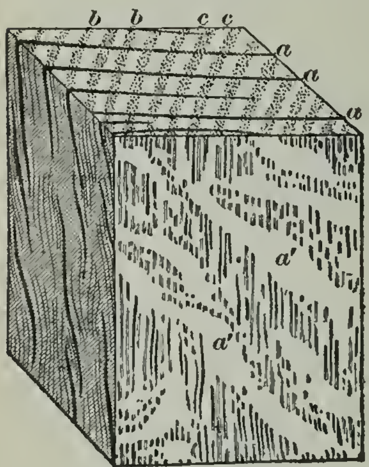


FIG. 2.

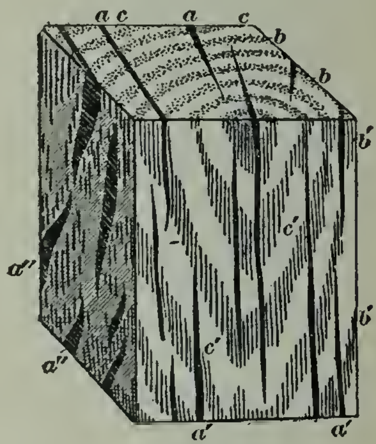


FIG. 3.

face grain of the laminations, as shown at b' and c' in Fig. 3. The advantages in quarter sawing material having well-defined medullary rays are that it wears better, shrinks less, and the silver grain presents a very fine effect.

Fig. 4 illustrates four methods of cutting the boards from the "quarters." The tree is first quartered by cutting it on lines *a b* and *c d*, after which the quarters may be reduced to boards by any of the methods shown. The best results are secured by the method shown between *a* and *c*, as the saw cuts are nearly on radial lines, and the full face of the silver grain will be exhibited.

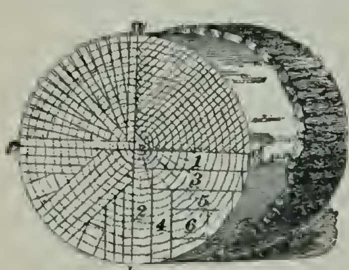


FIG. 4.

The section between *c* and *b* shows the next best method; fewer triangular strips are formed, but the boards will not present as rich an effect, as many of the medullary rays are

cut obliquely. The result of cutting the section between *a* and *d*, while economical in material, will not give as good results as the two former methods. Where thick material is desired, the system of cutting shown on the section between *d* and *b* is adopted, the cuts being made in the order in which they are marked.

As before stated, the best effects are produced when the saw cuts come parallel, or nearly so, with the medullary rays; this is shown in Fig. 2. These rays on the end section are marked *a*, and are seen to cross the annual rings *b* and *c* at nearly right angles, so that the edges of these rings are exposed on the face, and through which the silver grain *a′* emerges. The value of quarter sawing does not consist merely in the beautiful figuring of the material, but as it places the medullary rays at right angles with the annual rings, it is found that the quartered material shrinks less than one-quarter as much in the width as the common-sawed stock. This is an invaluable virtue, which the joiner and cabinetmaker are not slow to appreciate. Quarter-sawed stock is also less sensitive to changes of temperature, and when once thoroughly seasoned and well put together, it makes an admirable finish both for interior treatment and furniture, and its beauty is greatly enhanced with age.

CARPENTRY JOINTS.

A *bevel-shoulder* joint (*a*), Fig. 5, is a mortise and tenon used to unite inclined to upright or horizontal pieces. It is made by cutting beveled shoulders on the inclined piece and a corresponding sinking in the cheeks of the mortise of a post or beam.

A *bird's-mouth* joint (*b*) is an angular notch cut in a timber to allow it to fit snugly over the piece on which it rests.

A *bridle* joint (*c*) is one in which the mortise is supplanted by a tongued notch and the tenon by a grooved socket. The *tongue*, called the bridle, is equal to about one-third the thickness of the timber.

A *cogged* joint (*d*), called also a *corked* joint, is made with

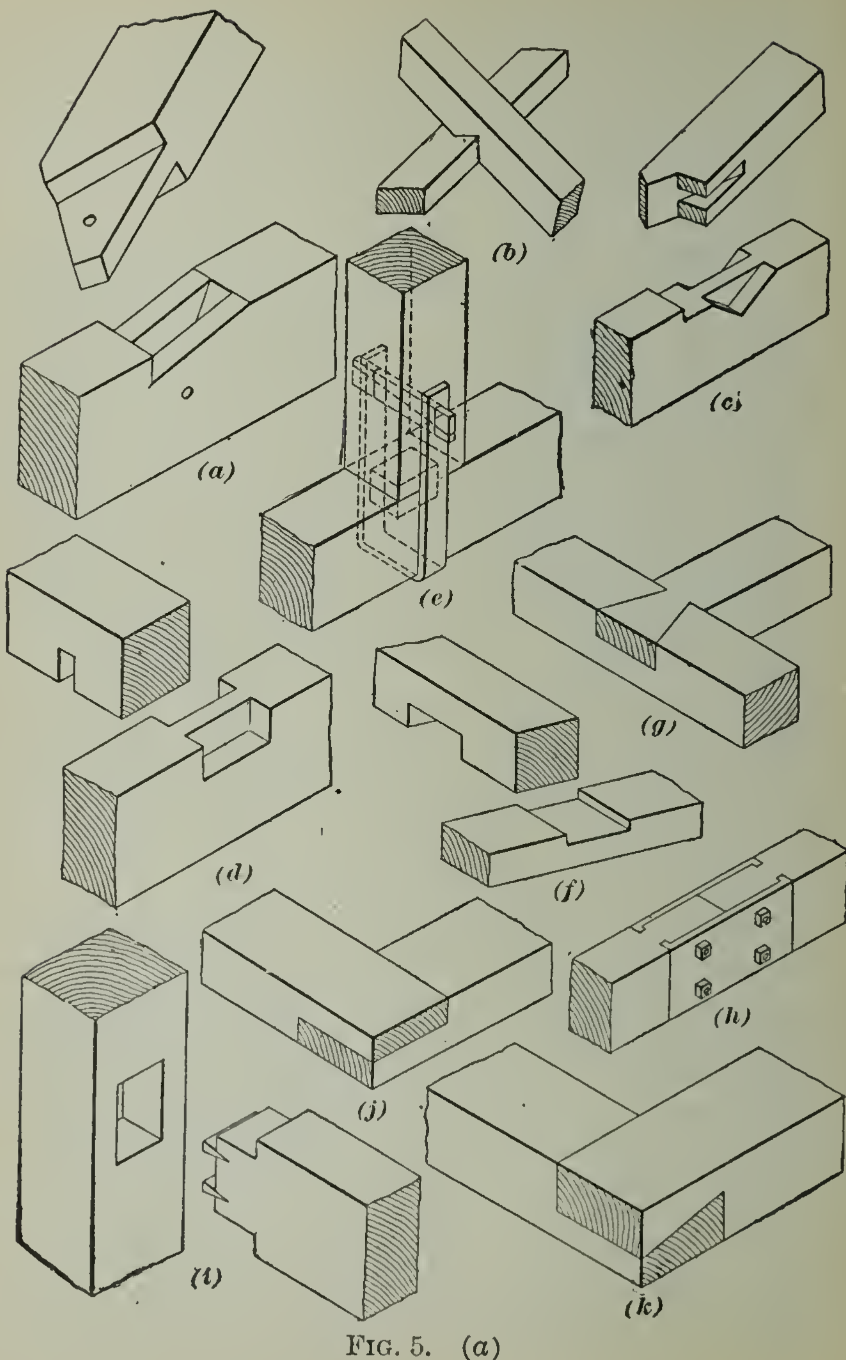


FIG. 5. (a)

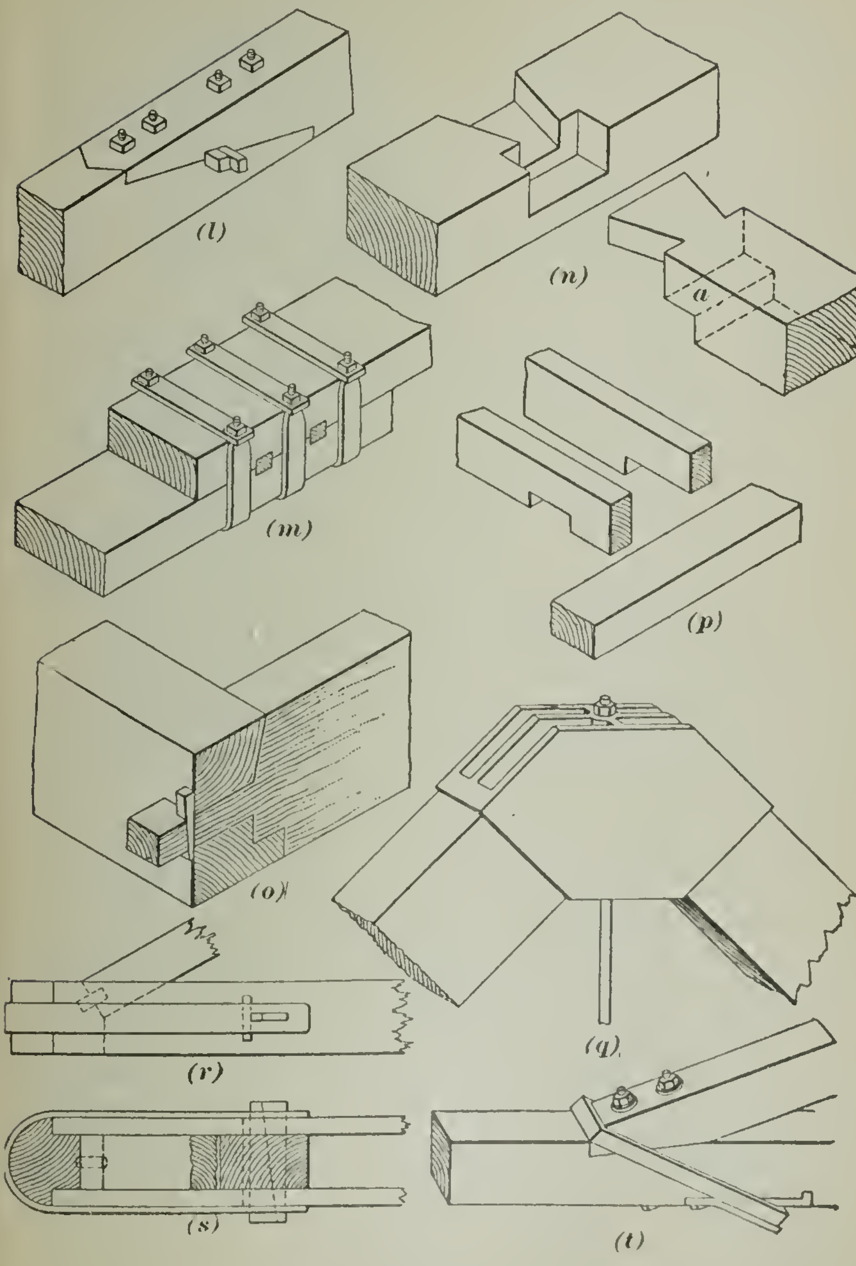


FIG. 5. (b)

a cog in the top of the lower timber, and a corresponding notch in the under surface of the upper timber.

The *cottered* joint (e) is used in tightening up tie-beams to king posts, etc., and consists of a steel strap and slip wedges.

In a *notched* joint (f), made by cutting a notch in each piece of timber, the notches are always less in depth than one-half the thickness of the material.

The *dovetail* joint (g), used to obtain a close, rigid union, consists of a wedged-like pin cut in the end of one piece, and a corresponding notch in the other.

A *fished* joint (h), used for joining timbers in the direction of their length, is formed by butting the squared ends together and placing short pieces of wood or iron, called fish-plates, over the faces of the timbers and bolting or spiking the whole firmly together.

The *fox-wedged* joint (i) is used to secure the tenon in a mortise that is not cut through. Thin wedges of hard wood are placed in saw cuts in the end of the tenon. On driving in the tenon the wedges cause it to expand and fit tightly in the mortise, which is dovetailed or widened out at the back.

A *halved* joint (j) is made by notching each piece one-half of its thickness, so that the top and bottom surfaces of both timbers are flush. Beveled or dovetailed halving is shown at (k).

The *scarf* joint (l) is used where the timber has to be lengthened; this joint forms a rigid splice.

A *lap* joint (m) is made by laying one end of a timber over another and fastening them together with bent straps, which have screw ends by which they may be tightened. The efficiency of this joint can be increased by inserting hard-wood tongues across the faces in contact.

The *lip* joint (n) is furnished with a lip a to make a stronger cross-section. It may also be applied to halved or dovetailed joints.

A *tusk-tenon* joint (o) is formed by inserting a tenon into a corresponding mortise. The tenon is strengthened by a shoulder at the root called a tusk. The tenon is generally one-sixth the thickness of the timber, and is placed midway in the depth. The upper shoulder is beveled so as to avoid

cutting away the material of beam into which it is inserted. This joint is a common one for uniting tail-beams to headers in floor framing.

A *checked* joint (p) is made when two pieces cross each other, and it is desired to reduce the height occupied by the upper timber.

The *socket* joint (q) is formed by inserting the ends of timbers into an iron casting. It is commonly used at the apex and toes of principal rafters. When used for the latter purpose, provision must be made to permit the evaporation of the sap.

The *strap* joint, shown in elevation and plan at (r) and (s), is made by girding the joint by a strong iron band. This joint is an approved method of tying the foot of a principal rafter to a tie-beam composed of two planks.

The *tie* joint (t) is one usually adopted to tie the inclined rafter to the tie-beam, and prevent it from spreading.

BALLOON FRAMING.

In this system of framing, timbers of small section are used to construct a light, skeleton frame, whose rigidity depends entirely on its thin, canvas-like covering. This is the distinguishing feature of balloon framing compared with braced framing, in which the rigidity depends upon a well-arranged system of mortise-and-tenon joints and diagonal bracing, irrespective of covering. A practical application of balloon framing is shown in Fig. 6, which is a perspective sketch of part of a building during erection. In this connection, a few points on good construction will be noted.

After the wall a is completed, the $4'' \times 8''$ sill b should be laid in a bed of lime mortar, tamped, and carefully leveled, as from it all heights are measured. The edge should be kept back from the face of the wall, so that the outside boarding will be flush with the latter. The sill should also be accurately squared, to obtain satisfactory results. A very simple and practical method of squaring depends on the geometrical principle governing right-angled triangles; namely, *the hypotenuse is equal to the square root of the sum*

of the squares of the other two sides. This principle is illustrated at the near corner of the sill in the figure. Lines are drawn on the top of the sill equidistant from the outer edges, and a nail is driven at their intersection. From this point 3 ft. is measured on one line and 4 ft. on the other, and nails are driven at the points marked. Where the pieces are square

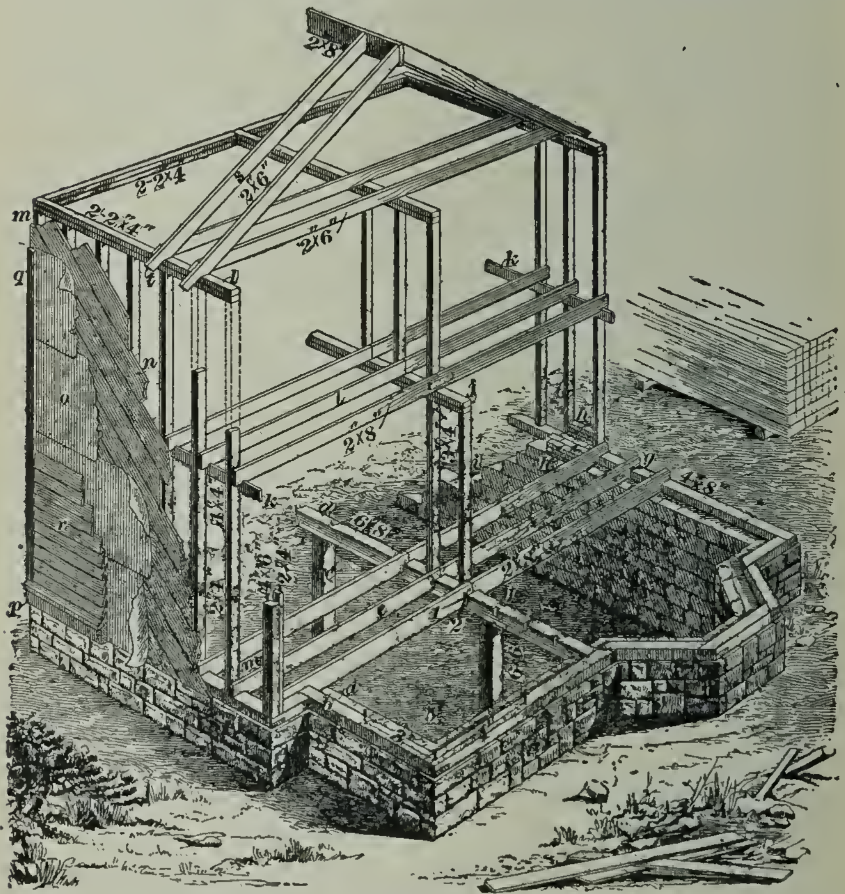


FIG. 6.

to each other, the hypotenuse will measure just 5 ft. Triangles with sides which are multiples of 3, 4, and 5, such as 6, 8, and 10, 9, 12, and 15, etc., may be used also.

The sill having been bedded, leveled, and squared, the cellar posts *c* are set up on base stones, and the beam *d* placed in position; the beam may be attached to the tops of the

posts by toe-nailing, but a more workmanlike method is to secure it by means of iron drift-pins, driven through the beam from above; or by inserting dowel-pins of wood or iron in the tops of the posts, and boring the beam to suit.

In order to reduce the depth of the wood liable to shrinkage, the top of the beam is kept up 4 in. higher than the lower edge of floor joists *e*, gains, or notches *f*, being cut out of its upper edge, into which seats the joists are fitted; unless this is done, the joists will be liable to split when loaded, as indicated at *1* and *2*. At the wall bearings *g* the joists are simply checked over the sill, but the heels or bearing of the joists on the wall should be supported by wedging up each one with a piece of slate, after the joist has been spiked to the sill and stud. The space between the joists should be filled in with stone or brick (usually the latter) up to the top of the joists, and 7 in. higher between the studs, as at *h*; this prevents the passage of air-currents and lodgment for rats and mice. To equalize the shrinkage at the bearing beam and wall sill, the joists should rest on top of the sill instead of being checked over it, as shown; but in common work this is seldom done, as 4 in. of effective height of the stud would thus be sacrificed. In order to provide for the inevitable shrinkage, the joists should be kept about $\frac{1}{4}$ in. higher at the center of the building. When 4″ studs are used, a firm, solid corner post can be made by nailing a 2″ × 4″ stud to the face of a 4″ × 6″ scantling.

The second tier of joists should be butt-jointed at the center partition *i*, toe-nailed into the plate *j*, and further secured from spreading by a fish-plate well nailed to each joist. Sometimes the joists are lapped over one another and spiked, which gives each joist a 4″ bearing on the partition; but this affects the equal spacing, and allows vibration, which may crack the plaster. Also, if hot-air pipes are to pass between the studs, the space thus contracted necessitates a narrower pipe, with less heating capacity. The wall ribbon is shown at *k*; over this ribbon are notched the joists *l*.

Where there are continuous partitions, the studs should be toe-nailed to the plate beneath and spiked to the second-floor joists. The plates being lapped and spiked to the plate

surmounting the wall studs, tie the building lengthwise, and stiffen the partition.

Before the building is sheathed, the corner posts *m* should be again carefully replumbed and adjusted by means of a plumb-bob suspended from the wall plate and run down to the sill, when the most accurate adjustment can be made. The sheathing *n* should be placed diagonally at an angle of 45°, and be well nailed to each stud with two or three nails, according to the width of the board. The butt joints should be cut on the center line of the studs. With boarding thus placed, well fitted and nailed, the structure is completely braced in a very simple and effective manner. The outer surface should be covered with a layer of heavy building paper *o*, lapped at the edges and tacked in place. Paper, being of close texture and a non-conductor of heat, makes an excellent covering material, rendering the building warmer in winter and cooler in summer. The base *p* should be capped to throw off the rain water, and should project about $1\frac{1}{8}$ in. outside the wall. The corner boards, as at *q*, $1\frac{1}{8}$ in. thick, should be firmly nailed in place, the inner edges being slightly beveled, so that the siding, when sprung in, will fit tightly. The siding *r* should be clear, white-pine boards, beveled on section, as shown, from $\frac{5}{8}$ in. thick at the lower edge to $\frac{5}{16}$ in. at the upper edge, and generally from 4 in. to 5 in. wide, according to the weathering, or exposed surface. The siding should have a lap of 1 in. or more, and should be nailed at each stud, the nails being of sufficient length to pass through the boarding and enter the stud; this gives better results than if they are simply driven into the sheathing. The *gauge*, or exposed width, of the siding varies where it comes in contact with door and window frames, in order that the horizontal lines of the siding will aline with those of the sill and head of the frame. Great care should be exercised in fitting the siding in place; when cut to the required length it should be somewhat longer than the distance between the vertical casings, in order that, when sprung into position, the end fibers will enter the edge wood of the casings, and thus insure a close joint, even after the casings have slightly shrunk.

SIZES IN INCHES OF FRAMING IN BUILDINGS.

Member.	Balloon-Frame Building.		Braced-Frame Building.		Slow-Burning Construction.
	Area, 1,500 Sq. Ft. or Less. 2 Stories High.	Area, Over 1,500 Sq. Ft. 3 Stories High.	Area, 1,500 Sq. Ft. or Less.	Area Over 1,500 Sq. Ft.	
Corner posts	2 × 4 spiked to 4 × 6	2 × 6 spiked to 6 × 8	2 × 6 spiked to 4 × 8	2 × 6 spiked to 6 × 8	10 × 10
Sills	4 × 8	4 × 10	4 × 10	4 × 10	6 × 10
Plates	Two 2 × 4	Two 2 × 6	6 × 8	6 × 10	6 × 10
Interties			4 × 8	6 × 8	8 × 10
Girts	1 × 4	$1\frac{1}{2}$ × 4			
Studs, bearing partition and opening	3 × 4	3 × 6	3 × 6	4 × 6	2″ to 3″ plank for partitions.
Studs, wall and partition	2 × 4	2 × 6	2 × 6	3 × 6	
Braces	2 × 4	2 × 6	4 × 6	5 × 8	6 × 8
Sheathing	1 × 9	1 × 9	1 × 9	1 × 9	Two $1\frac{1}{2}$″
Rough floor	1 × 6	1 × 6	1 × 6	1 × 6	3–$4\frac{1}{2}$
Finished floor	$\frac{7}{8}$ × 4	$\frac{7}{8}$ × 4	$\frac{7}{8}$ × 4	$\frac{7}{8}$ × 4	$\frac{7}{8}$–$1\frac{1}{4}$
Floor joists	2 × 8 to 3 × 10	2 × 10 to 3 × 12	3 × 8 to 3 × 12	3 × 10 to 3 × 12	4 × 10 to 10 × 12
Rafters	2 × 6 to 2 × 8	2 × 8 to 2 × 10	2 × 8 to 2 × 10	3 × 8 to 3 × 10	4 × 10 to 8 × 10
Tie-beams	2 × 6	2 × 8	2 × 10	2 × 12	

ROOF FRAMING.

LENGTHS AND CUTS OF RAFTERS.

The first step is to lay out a roof plan on a board or sheet of drawing paper, to a scale of, say, $1\frac{1}{2}$ in. to 1 ft. Fig. 7 (a) represents such a plan of a roof of uniform pitch, the wing

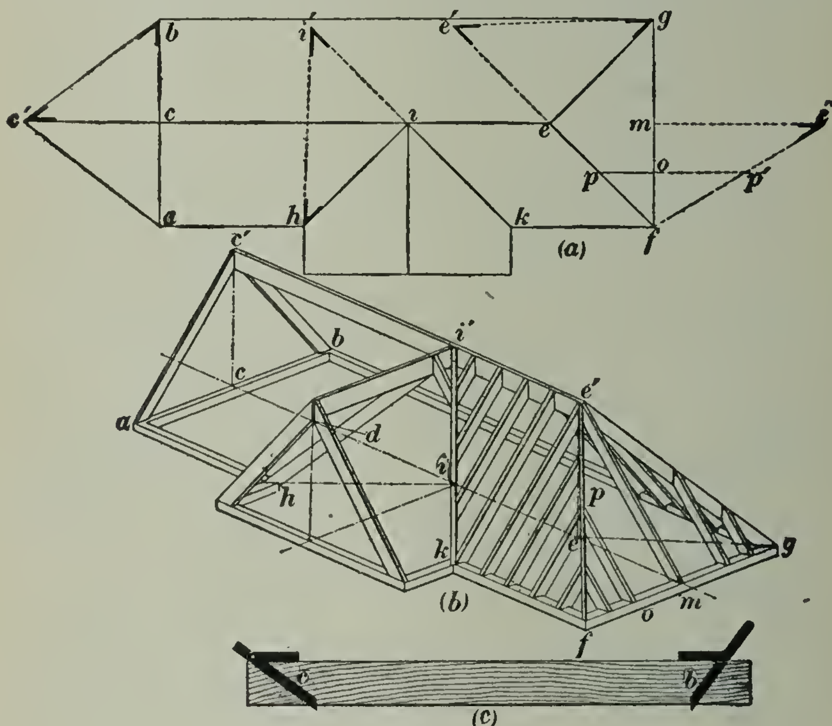


FIG. 7.

being the same width as the main building; one end of the roof is hipped, while the other ends are finished with gables, as may be readily understood by reference to the perspective view (b). In both views, the same letters refer to the same parts.

Length and Cuts of Common Rafters.—At the center of $a\,b$ in (a), erect a perpendicular $c\,c'$ equal to the height of the ridge above the wall plates; join c' and b; then, the angle at b is the foot-cut, and that at c', the plumb-cut of the common

rafters. The length may be found by sealing. The angles are transferred by means of a bevel to the rafter, as shown in (c), in which b is the foot-cut, and c the plumb-eut.

Length and Cuts of Hip Rafters.—On the line that represents the hip on plan—as $e\,g$ in (a)—ereet a perpendieular $e\,c'$ equal to the height $c\,c'$ of the ridge ; join c' and g ; the angles at c' and g are the plumb- and foot-euts, respectively, and the length may be found by scaling. The lengths and euts for the valley rafter $i\,h$ are in this case the same as for the hip rafter, and are found in the same way, as shown at h and i' in (a). Both hip and valley rafters have eheek-euts, which are the same as those of the jaek-rafters.

Length and Cuts of Jack-Rafters.— Erect a perpendicular $m\,e''$ at the eenter of the span $f\,g$; with f as a eenter, and $e'\,g$, the true length of the hip rafter, as a radius, strike an are eutting $m\,c''$ at e''; join f and e''; then the angle at e'' is the eheek-eut. The foot- and plumb-euts will be the same as for the eommon rafters. The length of any jaek-rafter, as $o\,p$, is found by prolonging it to eut $f\,e''$, as at p'; then $o\,p'$, measured by seale, is the length of $o\,p$.

Cheek-Cut for Rafters of Any Pitch.—On the faee of the rafter draw the plumb-cut, as at $a\,b$, Fig. 8 ; parallel to $a\,b$ draw $d\,e$

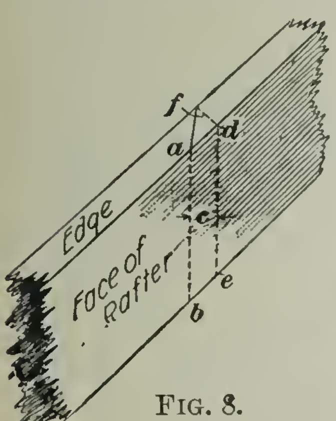


FIG. 8.

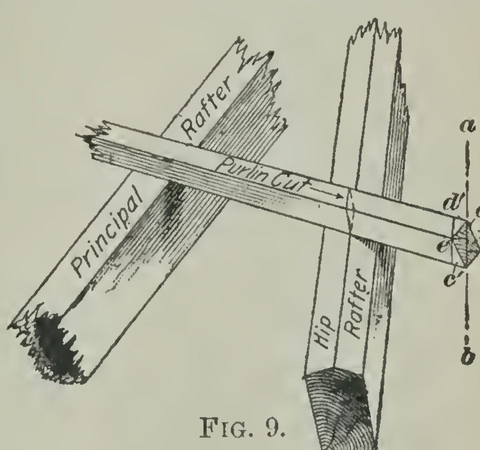


FIG. 9.

at a distance c equal to the thickness of the rafter ; square over from d to f, and join f and a, thus obtaining the cheek-cut.

Lengths of Hip or Valley Rafters; Wall Plates at Right Angles. Having fixed the rise and run by the square for the common rafter, take 17 in. for the run of the hip or valley rafter. Thus, if the roof is one-third, i. e., 8 in. rise and 12 in. run, the hip or valley rafters will have the same rise, 8 in., and 17 in. run. This rule gives results too great by about $\frac{5}{16}$ in. in 10 ft.

Lengths of Jack-Rafters.—Having obtained the lengths of the first two adjacent jack-rafters at the toe of the hip rafter, by the graphic or other method, measure the difference between their lengths, and keep adding this difference for the subsequent ones.

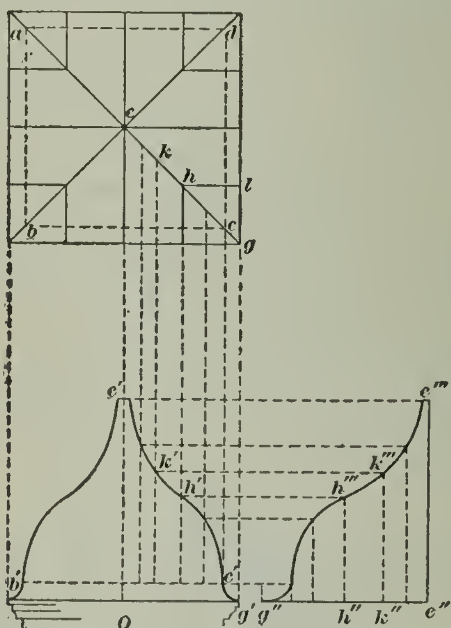


FIG. 10.

Miter Cuts for Purlins. On the squared end of the purlin draw a plumb-line, as at *a b*, Fig. 9. Draw perpendiculars, as *c* and *d*, from the corners of the purlin to this line. On the upper edge of the purlin lay off a distance *d'* equal to *d*, and on the lower edge lay off *c'* equal to *c*; from *e* draw lines to the points marked, thus obtaining the lines for the cut. This is for a cut over a hip rafter; where the cut is over a valley rafter, the bevel will be the same, but *d'* is laid off on the lower, and *c'* on the upper, edge.

Profiling Hip and Jack Rafters for a Curvilinear Roof.—In Fig. 10 the arrangement of the rafters is shown in plan, *e g* being a hip rafter, and *h l* a jack-rafter. In the elevation, *b' c'* is the span and *o c'* is the rise. To find the shape of the hip rafter *e g*, make *e'' g''* equal in length to *e g*, and lay off *e'' k''*, *k'' h''*, etc., equal to *e k*, *k h*, etc. Erect perpendiculars at *e''*, *k''*, *h''*, etc. At *e*, *k*, *h*, *c*, etc., drop perpendiculars

cutting the curve $e' g'$ at k', h'; etc. From k' h', etc. draw horizontals cutting perpendiculars from e'', k'', h'', etc., at the points e''', h''', etc. A curve drawn through these points gives the required outline of the hip rafter. The shape of the jack-rafter $h\,l$ is the same as the curve $h' g'$.

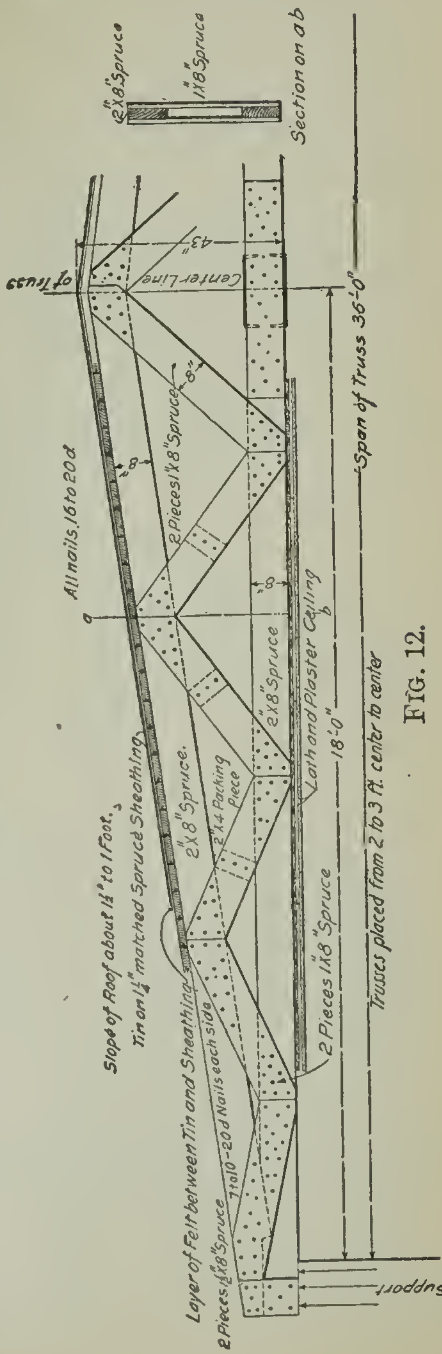


FIG. 12.

PITCHES FOR A GAMBREL ROOF.

A method of determining the pitches for a gambrel roof is shown in Fig. 11. The line

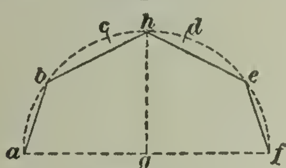


FIG. 11.

$a\,f$ is made equal to the width of the front plus the eave projections. On the center g, with a radius equal to one-half of this measurement, describe a semicircle $a\,h\,f$; divide this into five equal parts, as at b, c, d, and e, and erect $g\,h$ perpendicular to $a\,f$. Draw $a\,b$ and $f\,e$, the side slopes, and $b\,h$ and $e\,h$, the upper slopes; then $a\,b\,h\,e\,f$ will be the outline of the roof.

A PLANK TRUSS.

Fig. 12 shows a trussed rafter suitable for a flat pitch roof of from 30 to 40 ft. span, the rafters being set at from

2′ to 3′ centers. The rafters and joists are 2 in. × 8 in., and of a good quality of spruce or hemlock. The lattice braces are 1 in. × 8 in., and are placed in pairs, one on each side of the main members, to which they are spiked. The spiking should be well done, especially near the supports. The tie-member is spliced at the center of the span by two 1″ × 8″ fish-plates, well spiked to the ceiling joist; two iron dogs, well driven in, further strengthen the splice. The roof is covered with 1¼″ × 6″ tongued-and-grooved surfaced spruce, then with a layer of felt, upon which tin is laid. All other necessary details of construction are shown in Fig. 12.

MISCELLANEOUS NOTES.

SIDING A CIRCULAR TOWER.

In covering a circular tower with beveled siding, as shown at (*a*), Fig. 13, it will be found, on bending the strip of siding around the cylinder, that the edges will creep upwards in the middle, as indicated at (*b*). This is owing to the slope of the back of the siding, next the sheathing, caused by its lapping over the upper edge of the strip underneath; so that it really forms part of a conical surface. It will be necessary to find the slope length of the cone, to serve as a radius to describe the curvature to which the lower edge of the siding should be cut. Draw a vertical center line *a b* in (*c*), representing the center line of

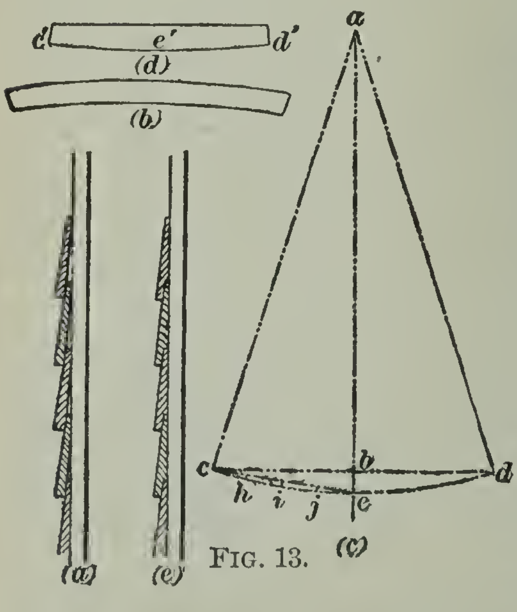


FIG. 13.

the tower, and at a point *b* draw *c b* and *b d*, each equal to one-half the diameter of the tower on the sheathing line, plus the thickness of the upper edge of the siding; from *c* or *d* draw a line towards *a*, having the same inclination as the back of the siding on the wall; the point where the line intersects *a b*, as at *a*, will be the vertex of the cone, and *a c* will be its slope length, and also the radius for describing the curve *c e d*. As the radius will be too long to lay down full size, any chord of the curve, as *c e*, may be used, from which offsets *h*, *i*, and *j* may be measured and laid down, so that the points can be fixed on the floor. A few wire nails being driven to mark the points, a flexible strip run around them will give a satisfactory curve, and the lower edge of the siding strip will be cut as at *c′ e′ d′* in (*d*), the curve of which is shown greater than it would be in practice, in order to emphasize it. The butt joints of the siding, as at *c′ d′*, being radial lines, must be cut square to the curve *c′ e′ d′*.

Should special siding with a straight back to hug the sheathing, as shown at (*e*), be used, no curvature will be required for the lower edge, as, in sheathing a cylinder, boards with straight, parallel edges can be used.

PROPORTIONS OF ROOMS.

Church Dimensions.—In figuring the floor area it is usual to allow from 5 to 7 sq. ft. for each person. This includes space occupied by passages, pulpit, etc. Width between pews, back to back, from 30 to 34 in. Length of seat allowed for adults, from 18 to 24 in.; for children, from 14 to 16 in.; height of seat, 18 in.; width, from 13 to 15 in.

Schoolrooms.—Width, from 16 to 24 ft. Height of level ceiling, 12 ft.; if floor area exceeds 360 sq. ft., 13 ft.; and if over 600 sq. ft., 14 ft. In one-story structures, where ceiling can be raised to tie-beams, the height to wall plate may be 11 ft., and to tie-beams 14 ft. Height of window sills from floor, 4 ft. Length allowed for seats of junior classes, from 14 to 18 in.; for senior classes, from 20 to 24 in. Distance apart for desks, back to back, 30 in.

Acoustic Proportion of Rooms.—Height 2, width 3, length 5 or 6; or add height of platform to height of speaker, and half the width of the room for the height.

Stable Dimensions.—Width for building with one row of stalls, 18 ft., occupied as follows: Hay rack, 2 ft.; length of horse, 8 ft.; for harness hanging against wall, 2 ft.; gutter, 1 ft.; and passageway, 5 ft. Height from floor to ceiling, from 12 to 16 ft. Width of stalls, from 5 ft. 9 in. to 6 ft. Loose boxes should be equal to at least two stalls. Stable doors, 4 ft. wide × 8 ft. high. Coach-house doors, from 7 to 8 ft. wide and 10 ft. high. Where practicable dispense with ceiling and place ventilator over each horse's head. Corn bins should be lined with galvanized sheet iron. Glazed brick make bright and healthful walls; desirable tints are buff, cream, light green, and French gray. Paving should be of concrete or clinker brick. Stalls should have a fall of 4 in. toward gutter. Harness room should be isolated from the stable, and is usually placed between the stable and coach house.

FLAGPOLES.

For a flagpole extending from 30 to 60 ft. above the roof, the following proportions give satisfactory results: The diameter at the roof should be made $\frac{1}{50}$ the height above the roof, and the top diameter $\frac{1}{2}$ the lower. To profile the pole, divide the height into quarters; make the diameter at the first quarter $\frac{15}{16}$ of the lower diameter; at the second quarter. $\frac{7}{8}$; and at the third quarter, $\frac{3}{4}$. Thus, if a pole is 41 ft. 8 in. high above a roof, the lower diameter is $\frac{1}{50}$ of 41 ft. 8 in., or 10 in.; that of the first quarter, $9\frac{3}{8}$ in.; the second, $8\frac{3}{4}$ in.; the third, $7\frac{1}{2}$ in.; and the top, 5 in.

Flagpoles may be made of spruce or pine; Oregon pine is preferable, and where the entire sap-wood is removed by cutting the pole out of the heart of a large trunk, a durable pole is obtained. The pole should be painted with at least four coats of white lead, and should be capped by a suitable finial, terminating in a gilded ball. Halyards should be at least $\frac{1}{2}$ in. in diameter, and be of waterproofed, braided cotton, or Italian hemp.

PREVENTION OF DECAY.

The destructive effect of water in causing rot of woodwork is well known, and precautions must be taken, in the construction of exposed surfaces, to lessen this result as much as possible. A few of these points are noted below.

The decay of veranda posts resting on the floor is due to capillary action; every time there is a shower or the floor is washed, some water finds its way under the post and is absorbed. This can be avoided by the interposition of an iron shoe, to keep the post from contact with the floor.

Water running down the faces of projections, as window sills, lintels, etc., at first drops off at the lower angle, but gradually forms a film across the projecting under surfaces; the drops are thus attracted into the stone or brick wall or the woodwork, as the case may be, causing disintegration of the mortar or decay of the wood. A simple preventive for this action is to groove or throat the under side, near the edge, causing the water to drip from the line of the groove. The necessity for this exists where there are horizontal projections exposing an under surface, such as water-tables, sill and lintel courses, copings, cap or drip members, and molded bands or cornices, whether of wood or stone.

The lower sash of windows, unless properly constructed and kept well painted, suffers through capillary action. If a film of water is allowed to form between the sills of the window frame and sash, it readily follows the vertical grain of the stiles; while the wind forces in rain until the inner sill is also wet. This may be prevented by forming grooves on the sill of the window frame and on the lower edge of the sash, as shown in Fig. 14.

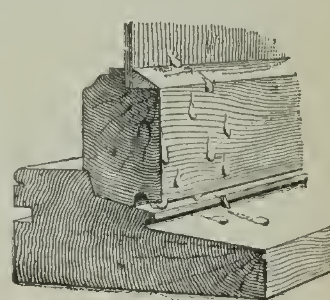


FIG. 14.

Water absorbed between slates or shingles rusts the nails securing them, and also rots shingles. For this reason, slates too fine in texture are not as good as rougher ones, as the closer the contact of the surfaces, the better does capillarity

act. Sawed shingles are not as good as split ones, the woolly surfaces retaining moisture, and being more favorable to its ascent. Shingled roofs should neither be close-boarded nor have the shingles underlaid with paper, in order that the air may circulate and dry them more readily. Shingles should be well dipped in creosote before being laid, and afterwards thoroughly coated with it, to render them as impermeable as possible. Metal-roof flashings and valleys present surfaces between which water will creep up, and, unless they are made of sufficient width or height, the roof will not be water-tight.

STEEL SQUARE.

The standard steel square, shown in Fig. 15, is the one known to the trade as No. 100, but catalogued by some dealers as No. 1,000. The square consists of two parts, the blade, generally 24 in. long and 2 in. wide, and the tongue, usually 18 in. long and 1½ in. wide. The outside edges on one face are divided into inches and sixteenths, and on the other face the inches are divided into twelfths. On the inside edge the graduations are to eighth inches on one side and to thirty-seconds on the other.

On the tongue, near its junction with the blade, Fig. 15 (*b*), will be seen a diagonal scale (shown enlarged in Fig. 16), used for taking off hundredths of an inch. The line ab is here 1 in. long, and is divided into 10 parts; the line cd being also divided into 10 parts, diagonal lines are drawn connecting the points of division as shown. For example, to take off .76 in., count off *seven* spaces from c, cg equaling .70 in.; now count up the diagonal line until the *sixth* horizontal line ef is reached; then ef is equal to .76 in.

On the same side of the tongue is the brace scale, which may be seen at *C*, Fig. 15 (*b*). This scale gives the length of a brace of given rise and run, or, in other words, the length of the hypotenuse of a right-angled triangle with equal sides. For instance, the hypotenuse of a triangle each of whose sides is 57 in., is 80.61 in. The length and end cuts for a brace of any rise and run may be found by using the square in a similar manner.

On the blade, Fig. 15 (*b*), is shown the board-measure scale, the use of which will be explained by aid of an example. Let it be required to find the number of board feet in a $1'' \times 7''$ board, 13 ft. long. Under the 12″ mark, find the number *13*, and follow the horizontal space in which *13* is found to the 7″ mark; the answer is there found to be $7\frac{7}{12}$ ft. B. M. If the board is over 1 in. thick, the problem is solved in

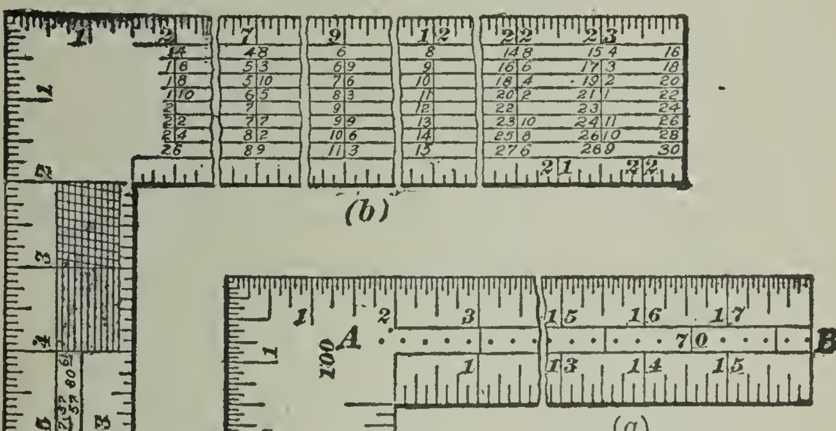
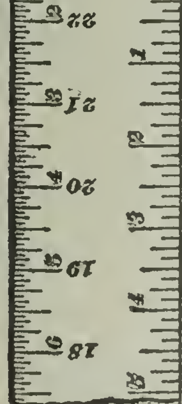



FIG. 15.

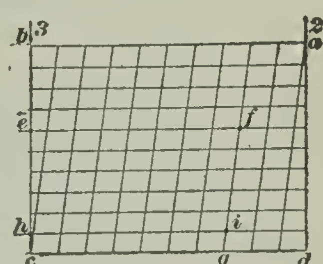


FIG. 16.

the same way, the result being multiplied by the thickness in inches. If the length of the board is greater than any number given under the figure *12*, it should be divided into parts, as in the following example: Required the contents in board measure of a $2'' \times 9''$ plank, 23 ft. long. Divide the length into two parts, 10 ft. and 13 ft.; the contents of the 10′

part is found, as before shown, to be $7\frac{6}{12}$ ft. B. M.; that of the 13′ board to be $9\frac{9}{12}$ ft. B. M. Therefore the total contents (if 1 in. thick) is $7\frac{6}{12} + 9\frac{9}{12} = 17\frac{3}{12}$ ft. B. M.; but as the board is 2 in. thick, the contents are $2 \times 17\frac{3}{12}$, or $34\frac{1}{2}$ ft. B. M.

The octagonal scale, found on the tongue at *A B*, Fig. 15 (*a*), is used in inscribing an octagon in a square. The scale is marked 10, 20, 30, etc. To inscribe an octagon in a 12″ square (see Fig. 17), draw the lines *a b* and *c d*, bisecting the sides; from *d* mark *d e* and *d f*, each equal to 12 divisions on the octagonal scale; mark *b g*, etc., in the same way, and draw *e g*, a side of the required octagon. The other sides may be similarly found. For a 10″ square, make *d e* equal to 10 divisions; for a 7″ square, equal to 7 divisions, etc.

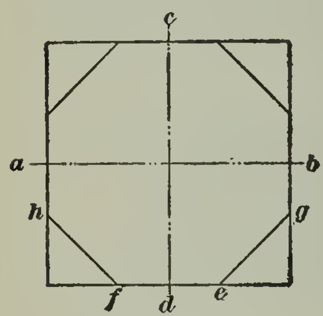


FIG. 17.

In Fig. 18 (*a*) is shown an adjustable *fence*, a strip of hard

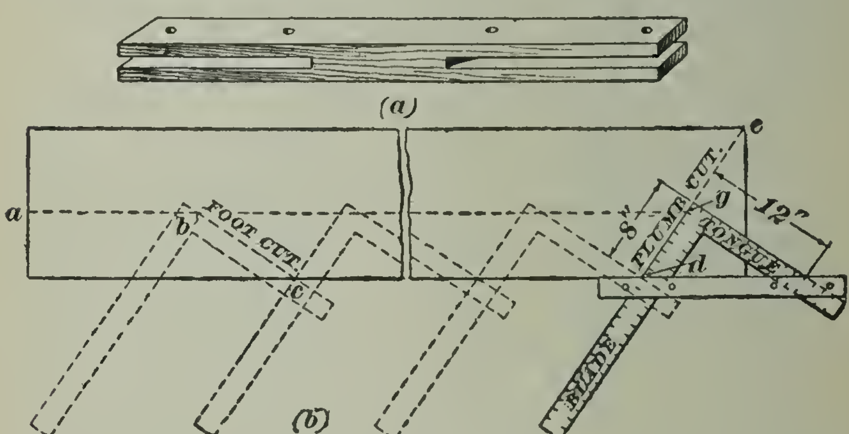


FIG. 18.

wood about 2 in. wide, $1\frac{1}{2}$ in. thick, and $2\frac{1}{2}$ ft. long. A saw kerf, into which the square will slide, is cut from both ends, leaving about 8 in. of solid wood near the middle. The tool is clamped to the square by means of screws at convenient points, as shown. Let it be required to lay out a rafter of 8′

rise and 12′ run. Set the fence at the 8″ mark on the blade, and at the 12″ mark on the tongue, clamping it to the square with $1\frac{1}{4}''$ screws. Applying the square and fence at the upper end of the rafter, we get the plumb-cut *d c* at once. By applying the square, as shown, twelve times successively, the required length of the rafter and the foot-cut *c b* are obtained. In this case the twelve applications of the square are made between the points *c* and *d*. Run and rise must also be measured between these points. If run is measured from the point *b*, which will be the outer edge of the wall plate, it will be necessary to run a gauge line through *b* parallel to the edge of the rafter, and subtract a distance *e g* from the height of the ridge, to give us the correct rise. The square must then be applied to the line *b g*. A rafter of any desired rise and run may be laid off in this manner by selecting proportional parts of the rise and run for the blade and tongue of the square. For a half-pitch roof, use 12 in. on both tongue and blade; for a quarter-pitch, use 6 in. and 12 in.; for a third-pitch use 8 in. and 12 in., etc. The terms half-pitch, quarter-pitch, etc., refer to the height of the ridge expressed as a fraction of the span.

JOINERY.

JOINTS IN JOINERY.

A *beaded* joint (*a*) Fig. 19, is one disguised by a quirked bead which is worked on one edge; this joint is used in matched lining, etc.

Butt joints (*b*), (*c*), and (*d*), are used for returns, when one piece is fitted to the edge of another, and may be rebated, matched, or plain-butted, as required.

The *feathered* or *slip-tongue* joint (*e*), formed by plowing corresponding grooves in adjacent pieces and filling it with a slip tongue, is generally employed for plank flooring.

A *grooved, tongued-and-mitered* joint (*f*) possesses the qualities of strength and effectiveness, and no edge grain is exposed.

The *half-lap dovetail* joint (*g*) is a form in which the dovetails appear only on one side, and is the method adopted for drawer fronts.

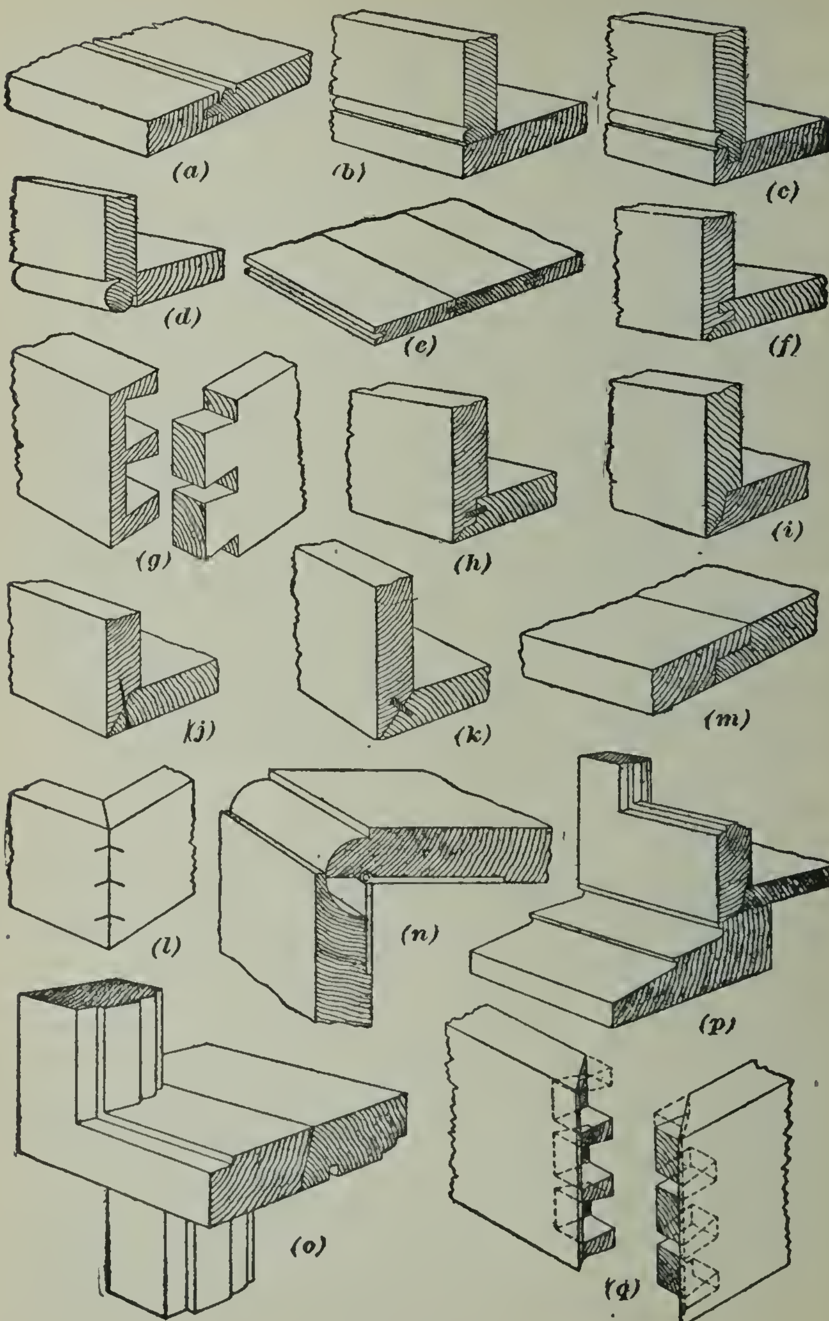


FIG. 19.

The *lapped-and-tongued miter* joint (h) is somewhat similar to (f), but a slip tongue is inserted instead of being worked out of the solid material.

A *lapped miter* joint (i) is made by rebating and mitering the boards to be joined, and securing them with nails.

A *miter-and-butt* joint (j) is a good form for an angle joint and is simpler than (i).

A *miter-keyed* joint is a miter strengthened by a slip feather, as at (k), or with slips of hard wood fitted into saw kerfs, as at (l).

A *rabbeted* joint (m) is formed by cutting rectangular slips out of the edges of the boards to a depth generally equal to one-half of their thickness, the tongues thus formed being lapped over each other.

A *rule* joint (n) is a hinged joint used for the leaves of tables, etc.

Beveled joints (o) and (p) are formed to close tightly and exclude the wind and water.

The *blind dovetail* joint (q), used for boxes and cabinets where the dovetails are not to show, is made by dovetailing three-fourths of the thickness of the board and mitering the other fourth.

DOORS.

Proportions.—The ratio between the width and height of doors at main entrances and in public buildings is usually as 1 to 2; that is, the height is twice the width. For single doors in dwellings and offices, the ratio should be as 1 to $2\frac{1}{2}$; or the height should be $2\frac{1}{2}$ times the width; doors $2' 8'' \times 6' 8''$ and $3' \times 7' 6''$, are thus proportioned.

The width of a door is regulated by the purpose for which it is intended; in public buildings provision is made for the passage of several persons at a time, while in private houses and offices a width suitable for one person is sufficient. In the former case, the width may be from 6 to 14 ft., while in the latter, the general rule makes the minimum width 2 ft. 8 in. for communicating doors, and 2 ft. for closet doors. A hinged door more than 4 ft. wide should be made double; that is, in two folds. As double folding doors take up much

wall space when kept open, sliding doors are frequently substituted. Where there are several doors of different widths in the same room, to give a better effect to the interior treatment the height of the principal doors should be fixed by the proportion given, and the others made the same height. If the width of double or sliding doors does not exceed 6 ft., the height may be that of principal doors, but if wider, the height should be one-fourth more than the width. The width of sliding doors, however, is largely regulated by the depth obtainable for the pocket in the partition.

Framing.—The width of the stiles and top rail should be about one-seventh the width of the door, the bottom rail about one-tenth the height, and the muntins and lock-rails $\frac{1}{2}$ in. less in width than the stiles. The thickness will depend somewhat on the style of finish and the class of lock to be used. If the door framing is solid and rim locks are used, the thickness for chamber doors may be $1\frac{1}{4}$ in.; if mortise locks are used, the thickness should not be less than $1\frac{1}{2}$ in. Solid doors for principal rooms are made from $1\frac{3}{4}$ in. to 2 in., and entrance and vestibule doors from $2\frac{1}{4}$ in. to $2\frac{1}{2}$ in. thick. When doors are veneered, the thickness is usually increased $\frac{1}{4}$ in.

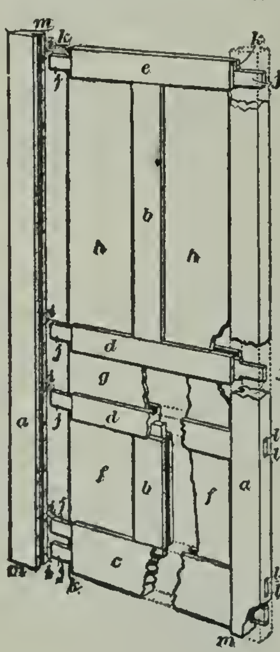


FIG. 20.

When mortise locks are used, the doors should, for strength, be framed with a lock-panel so that the joints adjacent to the lock will not be injured.

Construction.—The mode of constructing a 5-paneled door is shown in Fig. 20, certain parts being removed to clearly show the joints. The parts marked *a* are the outer stiles; *b*, the muntins; *c*, the bottom rail; *d*, the lock-rails; *e*, the top rail; *f*, the lower panels; *g*, the lock-panel, and *h*, the upper panels. The mortises *i* are made one-third the thickness of the framing into which the

tenons j are fitted. The edges of the framing are grooved $\frac{1}{2}$ in. deep, to receive the panels, the width of the groove being the same as the thickness of the tenon. The upper edge of the tenons of the top rail and the lower edge of the tenons of the bottom rail are haunched, as shown at k. The bottom rail has double tenons with a bridge between the mortises. The muntins are mortised into the rails. The panels should be kept from $\frac{1}{8}$ to $\frac{3}{16}$ in. less than the width of the space between grooves, to permit expansion.

In putting the door together, only the shoulder, or that portion of the tenon next the panel, should be glued, so that in case of shrinkage or swelling the joints will remain close. When the stiles are driven up and the clamps applied, the wedges l should be well fitted, should have the edges next the tenons brushed with glue, and be driven tightly in. The horns m, or extra lengths of the stiles during construction, are designed to withstand the pressure exerted when the end wedges are driven in, which would otherwise be forced out by shearing the fibers of the wood beyond the mortise, thus destroying the joint.

Fitting.—The width of the door should be about $\frac{3}{16}$ in. less than the width between the jambs, allowing a clearance of about $\frac{3}{32}$ in. on each side, and the opening edge should be slightly beveled. The standard bevel to which locks are made is $\frac{1}{8}$ in. in $2\frac{1}{4}$ in., but where the door is narrow, it may require the lock-face beveled to as much as $\frac{1}{4}$ in. in 2 in., or even more. An equal clearance should be left at the upper rail, while the bottom rail may require from $\frac{1}{4}$ in. to $\frac{1}{2}$ in., in order that the door may swing clear of the floor covering. Where "saddles" are used—which are not to be recommended—the door may fit within $\frac{3}{32}$ in. An appreciable amount of the clearance will be taken up by the layers of paint or varnish.

Butts.—A simple rule for finding the width of butt required for any door is: *To twice the thickness of the door, less $\frac{1}{8}$ in., add the greatest amount of projection of any part of the door casing beyond the face line of the door (which is usually the base block).* Thus, if a door is 2 in. thick, and the base block projects $1\frac{7}{8}$ in., the width of the butt will be 2 in. + 2 in. − $\frac{1}{8}$ in. + $1\frac{7}{8}$ in.,

or $5\frac{3}{8}$ in., in which case a $5\frac{1}{2}''$ width would be used. The edge of the butt will thus be kept $\frac{1}{4}$ in. back from the face of the door. One-half of the thickness of the butt should be cut out of the door, and one-half out of the jamb of the frame. In locating the butts, it is usual to keep the lower end of the lower butt in line with the upper edge of the lower rail, while the top end of the upper butt may be kept from 6 to 7 in. below the upper edge of the top rail. Where three butts are used, it is well to keep the lower end of the intermediate butt in line with the upper edge of the lock-rail, instead of placing the butt midway between the upper and lower butts, as the butts will then line up with the framing. By keeping the pin of the lower butt slightly in advance of the upper butt, the door, in opening, will rise at the toe and increase the clearance, so that inequalities in the floor level may be overcome. For first-class working doors the following conditions must be observed: *first*, the floor must be level in every direction; *second*, both jambs of the door frame must be accurately plumbed, facewise and edgewise, else the toe of the door will either rise above or fall towards the floor when operated; *third*, the head-jamb, or transom, as the case may be, must be level; *fourth*, the butts must be of good quality, well fitted, and the pins kept true to line.

WINDOWS.

Area.—The following proportions are given by different authorities for fixing the amount of window surface: (1) One-eighth of the wall surface should be windows. (2) The area of glass should equal at least $\frac{1}{10}$ of floor area. (3) One square foot of glass should be allowed to 100 cu. ft. of interior space to be lighted. It is better to have a surplus than a deficiency of light, as if too bright, it can be regulated by blinds or shades.

Design.—The height of the window should be twice its width. Architraves should be from $\frac{1}{6}$ to $\frac{1}{7}$ the width of the window opening, and where pilasters adjoin architraves their width should equal that of the latter. Where consoles are used their length should not be less than $\frac{1}{3}$ nor greater than $\frac{1}{4}$ the width of the opening. The entablature should

be from $\frac{1}{4}$ to $\frac{1}{8}$ the height of the opening. Where engaged columns flank windows, at least $\frac{3}{4}$ of the column should project beyond the face of wall.

To obtain a uniform frieze line around rooms in dwellings, it is well to keep the window and door heads equidistant from the ceiling. Thus, where the walls are 10 or $10\frac{1}{2}$ ft. high, and the doors 8 ft. high, the top of the casing is from 18 to 24 in. from the ceiling. This space may be occupied by frieze and cornice, or a picture mold may extend around the room in line with the upper edge of the door and window casings. Where ceilings are not over 14 ft. high, this same effect can be obtained by introducing transom sash over the doors, filling these with either chipped plate or art glass.

The glass line of windows in dwellings should be about 30 in. from the floor for principal rooms, and about 36 in. for bedrooms. In all cases, the heads of windows should be as near the ceiling as the construction and interior scheme of treatment will permit, to obtain better light and ventilation. The meeting rails of window sash should be placed not less than 5 ft. 9 in. above the floor; otherwise, the rail will be on a level with the eyes, obstructing the view and detracting from the effect of the window. On this account the height of the upper sash is sometimes made only $\frac{1}{2}$ that of the lower, or $\frac{1}{3}$ the clear height. For buildings of any pretensions, it is a mistake to cut up the sash into small panes. It should be remembered that windows are designed for the purpose of lighting, and all obstructions created by sash bars detract from the desired result. Where the designer prefers to have window sash subdivided, metallic bars of zinc, copper, or lead will be found more durable than wood, and will not take up so much of the daylight area.

Sashes should slide vertically, counterbalanced by means of cord, chain, and weights, or by spring sash balances. Those that are hinged and open inwards cannot be made water-tight, and those opening outwards are likely to be injured by the action of wind, so that for general service the best results are obtained by use of sliding sash. Sash stops should be fastened with screws passing through slotted sockets, thus preventing the sashes from rattling and warping.

Construction.—In Fig. 21 is shown a view of a window frame with sliding sash, adapted for a frame building. The pulley stile *a* may be from $1\frac{1}{8}$ to $1\frac{3}{8}$ in. thick, and should be tongued into the blind stop *b* and the plaster casing *c*, each of which is $\frac{7}{8}$ in. thick. These tongues make the stiles rigid, preventing them from deflecting sidewise when the sashes are being operated. An open space of from 2 to $2\frac{1}{2}$ in. is left between the back of the pulley stile and the rough stud, thus forming a box for the weights. A movable pocket for the insertion of the weights is cut out of the *lower* portion of each pulley stile on the *inside*, so that it may be covered by the lower sash. The parting strip *d* is $\frac{1}{2}$ or $\frac{5}{8}$ in. thick, and passes into a groove $\frac{3}{8}$ in. deep in the pulley stile. The outside casing *e*, $1\frac{1}{8}$ in. thick $\times$ 5 in. wide, is firmly nailed through the blind stop into the pulley stile and to the wall sheathing. The inner face of the window frame is finished with a casing, which may be of any style of finish—in this case, by an architrave, the width being sufficient to cover the plaster joint. The sash stop *g*, from $\frac{1}{2}$ to $\frac{5}{8}$ in. thick, is secured with round-headed screws passing through slotted sockets for adjustment. The members *g*, *d*, and *b* should be kept in line, their projection beyond the face of the pulley stile being regulated by the thickness of the sash stop.

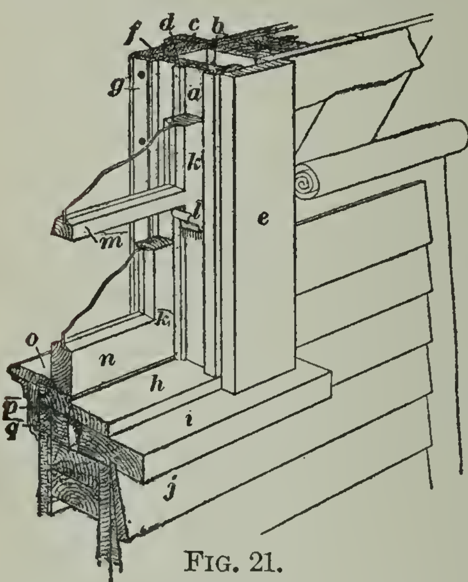


Fig. 21.

The sill *h*, from $1\frac{1}{8}$ to $1\frac{3}{8}$ in. thick, is tongued into the pulley stiles and well nailed. Sills are sometimes made with a straight inclined surface instead of being worked with two facias, as shown. When water collects on the sill, it is readily drawn under *n*, the lower rail of the sash, by capillarity, or driven in by wind; by raising the surface under the sash

above the level of the outer portion, and running a small rounded groove in the fillet, the effect of the wind is to divert the water outwards. Under *h* is placed the subsill *i*, $1\frac{7}{8}$ in. thick, which is attached to the pulley stile, and likewise grooved for the reception of the beveled siding *j*. For durable work, the window frames should be put together with stiff white-lead paint, particularly adjacent to the sill and subsill. The sashes *k* are made from $1\frac{3}{8}$ to $1\frac{7}{8}$ in. thick. Strength is added to the upper sash by the elongation of the stile, forming a molded horn, as by this device the tenon of the meeting rail *m* can be made equal to its thickness. The meeting rails, $1\frac{3}{8}$ to $1\frac{7}{8}$ in. thick, according to width of opening, may be double- or single-beveled, as shown, so that they will come tightly together when closed. The lower rail *n* may be from 3 to $4\frac{1}{2}$ in. wide, and should be accurately fitted to the sill; the outer edge should be clear about $\frac{1}{8}$ in., but the inner portion should be in contact with it, thus preventing the ready passage of water. The inner face should be rebated and beveled to fit the edge of the stool *o*. This stool should be rebated to form an air-tight joint, and be bedded in white lead. An apron *p* is fixed to the edge of the sill and to a plaster ground *q*, and finished with a bed mold as shown. The length of the apron should be equal to the width from out to out of casings, and have the moldings returned on same.

In Fig. 22 is shown a box-frame window, suitable for a stone or brick wall. The general design and construction of the frame and sash are similar to that shown in Fig. 21, the only changes being in parts that require to be adapted to a new condition. In *brick walls* it is usual to set the window frames during the erection of the walls, thus facilitating the plumbing of the brick jambs, particular care being taken to brace the frames, in order to keep them plumb and level. By keeping the blind-stop casing *a* 1 in. wider than the back lining *b*, the frame can be firmly held in place after the braces have been removed. The sill *c*, made of 3″ plank, is (or should be) bedded in haired lime mortar, or, for first-class work, stiff white-lead paint and white sand. The groove on the bed permits the formation of a mortar tongue, making it

practically air-tight; the slightest shrinking and warping of the sill allows the passage of air and water, unless this device is adopted. A $\frac{1}{8}''$ finished casing d may be attached to the inner frame casing e, after the building is ready for trimming, thus covering its marred condition. The window stool or seat f rests on furring strips, and is tongued into the sill, providing for its expansion and contraction; it is generally finished with a molded apron g. The jamb lining h is tongued into the finished casing, and the opening trimmed with a casing, such as i, nailed to the lining h and the rabbeted plaster ground j.

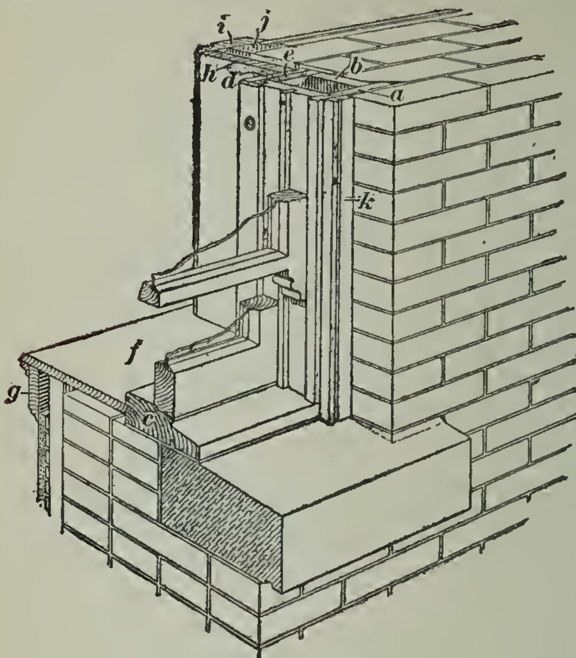


FIG. 22.

The hanging stile k in brick-set frames is attached thereto before setting, but where outside blinds are not used, an angle mold may be substituted.

In *stone walls*, window frames are not usually set until the building is roofed and either prepared for the plastering, or when the plastering has been completed. There are two reasons for this, the principal one being the difficulty experienced in setting jamb stones and lintels while the frame is in position, and the second that, with all due care, the frames are more or less damaged during building operations and are never so true to line, level, and plumb as those set in place after the walls are completed. When set in this latter order, it is necessary to encase the masonry openings with screeds or wooden strips, carefully alined and plumbed,

and so arranged to allow for a bed of haired mortar ½ in. thick around the jambs and window head. The frames are secured by means of holdfasts or wall plugs. When set in this manner, the casing *d* is not required, unless it be that the interior trim is of a material different from that of the window frame.

NOTES ON STAIRWAYS.

Proportioning Treads and Risers.—1. *Take the sum of two risers and subtract it from 24 inches; the result will be the width of the tread.* This rule is based on the assumption that an average step is 2 ft. and that the labor of lifting the foot vertically is twice that exerted in moving horizontally, consequently the width of the tread, added to twice the height of the riser, should be equal to 2 ft.

2. The first column of the accompanying table gives the width of treads; the other gives the corresponding height of risers.

Treads. Inches.	Risers. Inches.
6	8½
7	8
8	7½
9	7
10	6½
11	6
12	5½

3. *The product of the tread and risers should equal 66 inches:* thus, with a tread of 11 in. the riser would be 6 in.; with a riser of 7 in., the tread would be $9\frac{3}{7}$ in.

Miter Bevel for Stringer Cut.—The following method is of service in obtaining the accurate bevel to apply on the edge of a stair stringer, where it is desired that the riser miter with the stringer, as in an open string stairway. By the use of the pitch board, mark on the outside face of the stringer the cuts for the treads and risers, as in Fig. 23. Draw *b e* parallel to *a d*,

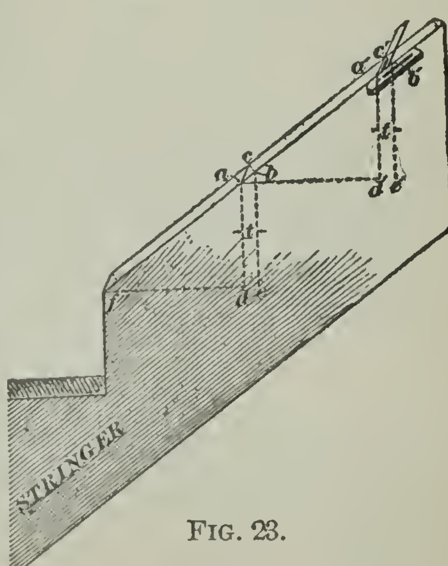


FIG. 23.

and at a distance t from $a\,d$ equal to the thickness of the stringer. At b, draw $b\,c$ square across the upper edge of the stringer, and connect c and a. Then $b\,a\,c$ is the miter bevel required. At a' is shown a bevel set to the line obtained, so that it can be used at all the other riser lines.

DEVELOPMENT OF A RAKING MOLD.

In Fig. 24 is shown a method for determining the cross-section of a raking mold to miter with a given eave mold. This method will apply equally well to any molding. The eave mold in this case is a cyma recta, the profile being shown as $a\,b\,f\,h\,j\,c$. Divide the outline into any number of equal parts, as at f, h, j, etc. Draw any horizontal line $l\,k$ and erect perpendiculars from f, h, j, etc., cutting the line $l\,k$. Draw $a\,l''$ at the required angle and draw $b\,e$, $f\,g$, etc., parallel to $a\,l''$. From any point l', lay off the distance $l'\,k'$ and subdivisions equal to $l\,k$. Drop perpendiculars to $a\,l''$ from l', k', etc. intersecting $b\,e$, $f\,g$, etc. Through the intersections thus found, trace the curve $l'\,c'$, which is the profile of the required mold.

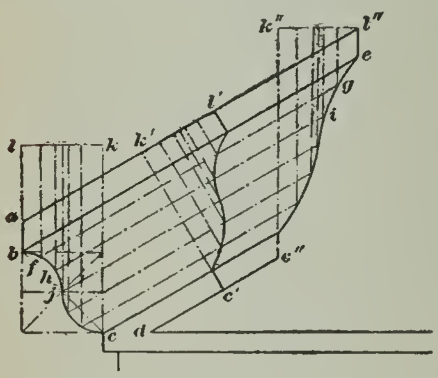


FIG. 24.

To find the profile of a vertical cut in the raking mold, at any point, as l'', lay off $l''\,k''$ and subdivisions parallel to $l\,k$. Proceed to find points e, g, i, c'', etc., as before.

HOPPER BEVELS.

In making hoppers or boxes with inclined sides, it is necessary to obtain the face and edge bevels; when the sides are mitered, the edge bevel is called the *miter* bevel, and when they are butted, it is termed the *butt* bevel. In Fig. 25 the diagrams are assumed to be laid out on a board, as if in bench practice.

In (a), let $c\,b$ be the width of a side of the hopper, and $c\,e$ the splay; let c be on the edge $k\,l$. Strike the arc $b\,j$, and draw $c\,j$ square to $k\,l$; then $c\,j$ is the width of the stuff. Lay out the thickness $b\,a$; draw $a\,d$ parallel to $c\,b$; also, $c\,d$ parallel to $b\,a$; and $c\,b\,a\,d$ will represent a section of the

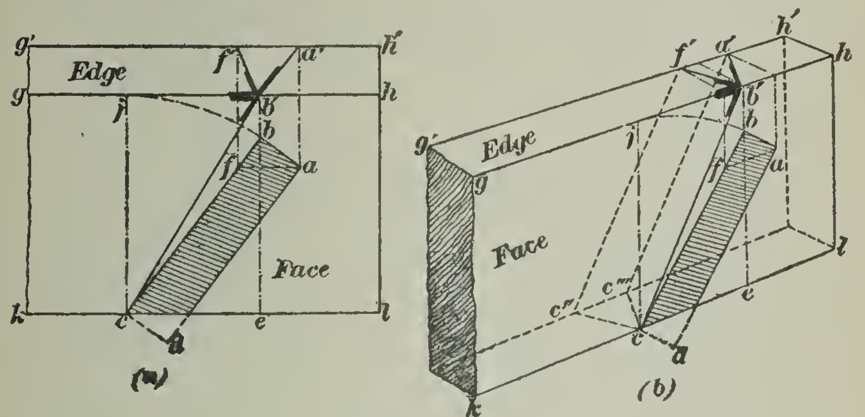


FIG. 25.

board. Project b to b', and draw $c\,b'$; then the angle $g\,b'c$ will be the face bevel. Make $h\,h'$ equal to $b\,a$, and draw $g'\,h'$; project a to a'; and draw $b'a'$, then $g\,b'a'$ will be the miter bevel. If the edges are cut off along the line $f\,a$, the miter bevel will be 45°.

If the hopper is to have butt joints, the face bevel is found as above shown. To obtain the butt bevel, proceed as follows: Draw $a\,f$ through a, parallel to $g\,h$; project f to f' on $g'\,h'$, and draw $b'f'$; then the angle $g\,b'f'$ will be the butt bevel.

In (b) is shown a perspective view of the board $k\,g\,h\,l$, with the bevels in position, $g\,b'\,c$ and $g\,b'\,a'$ being those required for a miter-jointed hopper, and $g\,b'c$ and $g\,b'f'$ those for a butt-jointed one. At $c''f'\,b'\,c$ is shown an outline of the butt joint, and at $c\,c'''a'\,b'$ that of the miter joint.

DIMENSIONS OF FURNITURE.

Chairs and Seats.—Height of the seat above the floor, 18 in.; depth of the seat, 19 in.; top of the back above the floor, 38 in. Chair arms are 9 in. above the seat. A lounge is 6 ft. long and 30 in. wide.

Tables.—Writing and dining tables are made 2 ft. 5 in. high. Dining tables extend from 12 to 16 ft., by means of a sliding frame. There should be 2 ft. clear space between the frame and the floor.

Bedsteads.—These are classed as single, 3 to 4 ft. wide; three-quarter, 4 ft. to 4 ft. 6 in.; and double, 5 ft. wide. All bedsteads are from 6 ft. 6 in. to 6 ft. 8 in. long inside. Footboards are 2 ft. 6 in. to 3 ft. 6 in., and headboards from 5 ft. to 6 ft. 6 in. high.

Other Furniture.—For *bureaus* convenient sizes are: 3 ft. 6 in. wide, 1 ft. 6 in. deep, 2 ft. 6 in. high; or 4 ft. wide, 1 ft. 8 in. deep, 3 ft. high. *Commodes*, or night stools, are 1 ft. 6 in. square on the top, and 1 ft. 6 in. high. *Chiffoniers* are 3 ft. wide, 1 ft. 8 in. deep, 4 ft. 4 in. high. *Cheval glasses* are made about 5 ft. 6 in. high, 2 ft. wide. *Washstands* of large size for portable bowl and pitcher are 3 ft. long, 1 ft. 6 in. wide, and 2 ft. 7 in. high. Small sizes are 2 ft. 8 in. long. *Wardrobes* are from 6 ft. 9 in. to 8 ft. high, from 1 ft. 5 in. to 2 ft. deep, and from 3 ft. to 4 ft. 6 in. wide. *Sideboards* are from 5 to 6 ft. long, about 2 ft. 2 in. deep and 3 ft. 3 in. high. *Upright pianos* vary from 4 ft. 10 in. to 5 ft. 6 in. in length, from 4 ft. to 4 ft. 9 in. in height, and are about 2 ft. 4 in. deep. *Square pianos* are about 6 ft. 8 in. long by 3 ft. 4 in. deep.

ROOFING.

SLATING.

A good slate should present a bright, silk-like luster, and should emit a clear metallic ring when tapped; if it is soft, it will present a dull, lead-like surface, and emit a muffled sound. When cut, the edges should show a fibrous-like texture, free from splinters, and the material should not show signs of being either brittle or crumbly. It is this element in slate, which may be called its *temper*, that largely defines its value; if brittle or too hard, the slate will be liable to fly to pieces when being squared and punched, or to be readily broken when being nailed in place. If the slate

is soft, it will, by absorbing moisture, be liable to be attacked by frost, so that the edges will crumble away, and the slates will work loose, owing to the nail holes becoming enlarged.

There are many varieties of color in slate, due to the presence of iron and mineralized vegetable substances. The pronounced colors are bluish black, blue, red, and green, while many tints of these shades exist, blending into grays and purples.

The commercial classification is based on straightness, freedom from curled and warped surfaces, smoothness of surface, and uniformity of color and thickness. The best way of judging the classification is to examine samples of the various grades. First-class slate should be hard and tough, non-absorbent, unfading, straight-grained, free from ribbons and other imperfections, and of uniform color throughout. No better test of the weathering qualities of slate can be contrived than the simple one of examining roofs where it has been in service for several years.

The sizes of slate range from 6 in. × 12 in. to 16 in. × 24 in., there being about 25 different sizes. The size to select depends on the character of the edifice and its location; for ordinary dwellings, a common size is 8 in. × 16 in. The thickness of slate is about $\frac{3}{16}$ in., or 5 to the inch; for extra-strong roofs, slates $\frac{1}{4}$ in. thick are used, while with the larger-sized slates, the thickness is $\frac{3}{8}$ in. or more. Slate weighs 175 lb. per cu. ft., and if $\frac{3}{16}''$ slates are used, the weight of the material on the roof will average $6\frac{1}{2}$ lb. per sq. ft. of surface covered. Slates are sold by the square, meaning that this quantity will cover 100 sq. ft. of roof surface; an ordinary railroad car has a capacity of between 40 and 50 squares.

The roof being devised for protection against the elements, particularly rain and snow, the steeper the pitch, the more effective will be its power to shed them; while the wind will not so readily blow rain under the courses, nor strip them off so easily. Where slates are small and light, and exposed to violent winds, the greater the necessity for increasing the pitch. Experience shows that the minimum pitch for slate roofs varies with the size of the slate. The pitch may be expressed either by the angle which the roof makes with the

horizontal, or by the ratio of the height of the ridge to tne span; the latter expression is the one generally employed. (See Table VII, page 68.) For large sizes of slate the pitch should not be less than 21° 50′, or one-fifth; for medium sizes, 26° 33′, or one-fourth; and for the smaller sizes, 33° 41′, or one-third.

Slates are laid on either strips or boarding; the latter costs the most, but the results justify the extra cost. Close boarding makes the roof a better non-conductor of heat, and is required for strength where thin slates are used. In Fig. 1 is shown a sectional view of a roof on a frame building, where the slates are nailed to strips *a*. These strips are usually from 1 to $1\frac{1}{4}$ in. thick and $2\frac{1}{2}$ or 3 in. wide, and are well nailed to the rafters; the distance between centers of the strips should be equal to the gauge or exposed portion of the slate. The lowest strip is thicker than the others, so as to tilt the first course enough to insure a close-fitting joint between the first two thicknesses. In commencing to slate, the first course is laid double, the lower course being laid with the back or upper surface of the slate downwards. The length of this course will be equal to the gauge plus the lap. The *lap* is the distance that the upper slate overlaps the head, or upper end of the second slate below it, and should not be less than 3 in., although slaters sometimes use only a 2″ lap. The *gauge* or exposed length of the slate is equal to half its length after deducting the lap.

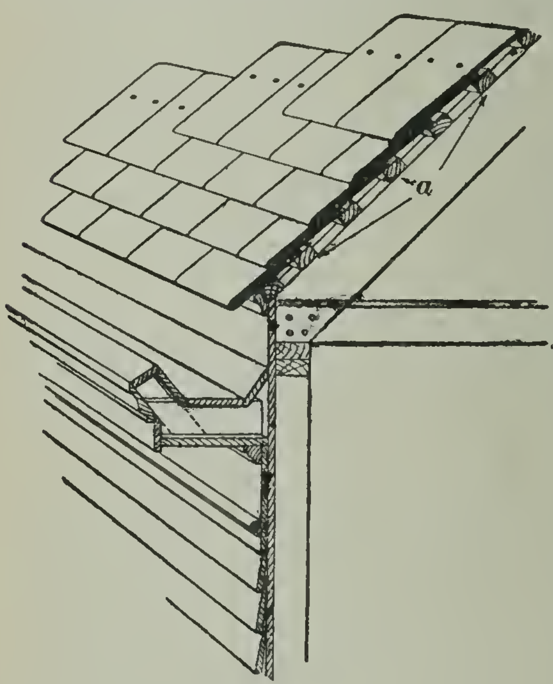


FIG. 1.

There are several ways of nailing the slate, either near the head or at the shoulder, in which the distance of the holes from the head will be slightly less than the gauge of the slate, to enable them to clear the head of the one underneath.

Another method of laying slate, where economy is desired, is that known as *half slating*, in which a space is left between the edges of the slate in each course equal to one-half the width of the slate. By this method, only two-thirds of the usual number are required to cover a given surface. This class of work is adapted for covering sheds, and while serviceable under ordinary conditions, will not be water-tight under the action of driving storms of rain and snow.

Slate nails have large flat heads, so as to have a good hold on the slate; their lengths vary with the thickness of the slate, and are usually called 3-penny or 4-penny*, having lengths of $1\frac{1}{8}$ in. and $1\frac{3}{8}$ in., respectively; the proper length should be twice the thickness of the slate plus the thickness of the boarding. To prevent rust, slate nails are usually galvanized iron or steel; sometimes they are tar-coated. For extra-good work, copper nails are used.

For other data on Slating, see page 351.

TIN ROOFING.

There are two kinds of tin-roof coverings in common use, namely, *flat seam* and *standing seam*. In the former method the sheets of tin are locked into one another at the edges, and nailed to the roof-boards as shown in Fig. 2. Six or eight 1″ wire nails are allowed to the ordinary sheet. The seams are flattened with wooden mallets and soldered water-tight. The seams constitute the weakest part

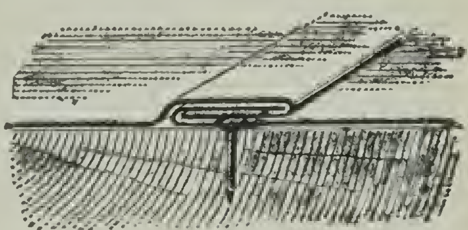


FIG. 2.

*The term *penny* as applied to nails is a corruption of the original form in which the nails were defined as 3-pound, 4-pound, etc., meaning that 1,000 of the nails weighed 3 pounds, 4 pounds, etc., respectively.

of a flat tin roof, and should therefore be made and soldered with great care. The tinner should not hurry the soldering, for time is required to properly "sweat" the solder into the seams. Resin is the best flux; chloride of zinc or other acids should not be used. A better method of fastening the sheets to the roof is by means of tin cleats about $1\frac{1}{2}$ in. $\times$ 4 in. These are nailed to the roof, and locked over the upper edge of the sheet, about 15 in. apart.

Standing-seam roofing is that in which the sloping seams are composed of two upstands interlocked, and held in place by cleats. They are not soldered, but are simply locked together, as shown in Fig. 3. The sheets of tin are first double-seamed and soldered together into long strips that reach from eaves to ridge. One edge is turned up about $1\frac{1}{4}$ in. and the other about $1\frac{1}{2}$ in. The cleats are placed about 15 or 18 in. apart. When the upstands and cleats are locked together the standing seam is about 1 in. high.

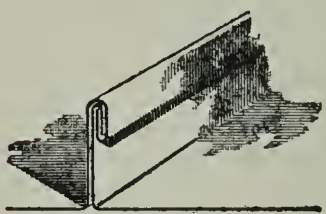


FIG. 3.

Before laying tin, the uneven edges of the boarding should be smoothed off and the boarding covered with at least one thickness of sheathing paper or dry felt, to form a cushion and otherwise protect the tin. Knot holes in the boarding should be covered with pieces of heavy galvanized iron. Only the best quality of tin should be used, and it should be painted on the under side before it is laid.

The outer edges of the tin should be turned over the upper edge of the cornice, and clasped to a strip of hoop iron; or, where it connects with a metal gutter, the two should be locked and soldered. Where a tin roof abuts a chimney or wall, the tin should be turned up sufficiently to prevent water from rising over it. This upstand should be counter-flashed with sheet lead; and abutting a wooden wall it should be turned up against the boarding, and the siding or shingles laid over it. The tin should also be turned up against all balcony posts, and the edges at the angles well soldered.

The roof should be painted within a few days after it is laid, either with red lead in linseed oil, or a good asphaltum paint, particular care being taken to scrape off all resin before the paint is applied.

There is little or no difference between the methods of laying tin or copper roofing. The most important point to be considered in copper roofing is to have the copper thoroughly tinned before commencing to solder it.

For other data on Tin Roofs, see page 353.

GRAVEL ROOFS.

The rafters should be spaced close enough to make the roof firm, when planked or boarded. For sheathing, tongued-and-grooved lumber is preferable; and in any case the plank or roof boards should be laid closely—making close joints, both at edges and ends—and should be free from holes or loose knots, and securely nailed to the rafters. Over the sheathing should be laid four layers of roofing felt, the first course, next the eaves, being five layers thick. Each successive layer should be lapped at least $\frac{2}{3}$ its width over the preceding one, and firmly secured with cleats. The quantity of felt per 100 sq. ft. of roofing should be not less than 70 lb. The surface under the outer layer of the first course, and under each succeeding layer, as far back as the edge of the next lap, should be well covered with a thin coating of cement, in no case applied hot enough to injure the woolly fiber of the felt. Over the entire surface should be spread a good coating of cement, amounting in all (including that used between the layers) to about 10 gal. per 100 sq. ft., heated as before specified. While the cement is hot, it should be completely covered with a coating of dry slag, granulated and bolted for the purpose, no slag being used that will not pass through a $\frac{5}{8}$-inch mesh, and none smaller than will be caught by a $\frac{1}{4}$-inch mesh. All chimneys and walls that project above the roof should be flashed and counterflashed with zinc or copper.

Gravel roofs form a very durable and inexpensive covering, but are not suitable for any but practically flat surfaces.

GUTTERS.

In Fig. 4 is shown a strong and durable box gutter, suitable for either a frame building or for a brick or stone structure, having a wooden cornice. A series of lookouts are nailed to the wall studs (or built into the brickwork or stonework), forming a solid base for the cornice and gutter. The width of the lookouts may be varied, to obtain the grade for the gutter bed, or it may be uniform, strips being nailed to the upper edges of the pieces. On a gable roof the cover-plate over the crown mold should be kept in line with the sheathing on the roof slope. In lining this gutter, if a strip of hoop iron is tacked to the fillet of the crown mold, with its lower edge kept ¼ in. below the mold, the lining may be tightly clasped over the strip, and face nailing dispensed with, thus making a neat and durable job. The lining should pass behind the eave mold, but need not be carried up the slope. The insertion of a triangular strip at the angle of the gutter bed and the wall is of advantage, as the

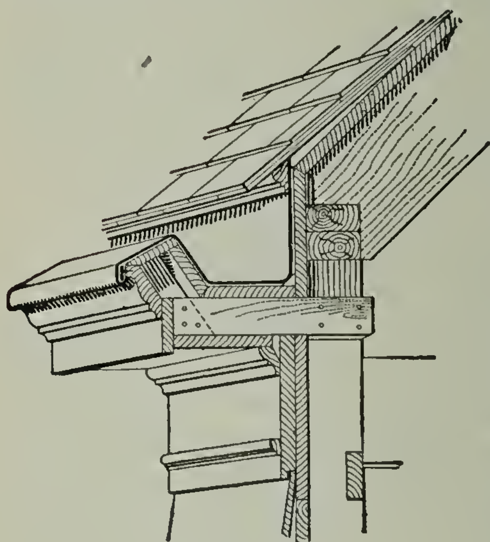


FIG. 4.

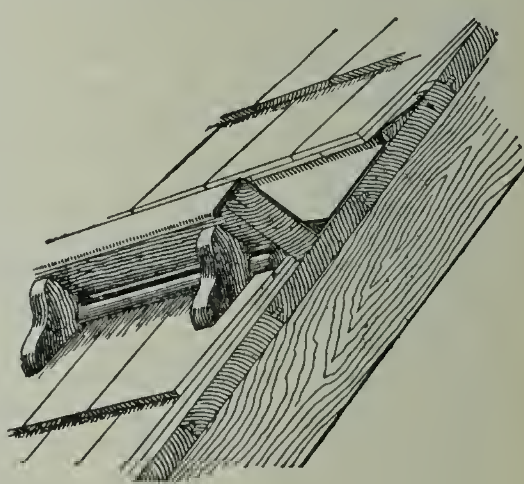


FIG. 5.

gutter is more readily cleaned by the wash than with a square corner. The end of the gutter is closed at the gable, so that the crown mold can run up the facia and be continuous; it is usual to leave a space of from 4 to 6 in. between the closed end and the gable facia.

Figs. 5 and 6 show methods of forming standing gutters, the former being adapted for shingled roofs, and the latter for either shingle or slate roofs. It is important to insert the tilting fillet in both cases, for two reasons: *First*, to obtain the tilt for the lower double course so that the bed of the second course will lie close to the back of the lower course; and *second*, to form a drip at the edge of the lower course, so that water will not be drawn up by capillary attraction under the shingle or slate and pass over the upper edge of the flashing. These are durable forms of gutters, but they have the disadvantage of acting as guards, retain snow on the roof, and mar to some extent the appearance of the roof planes.

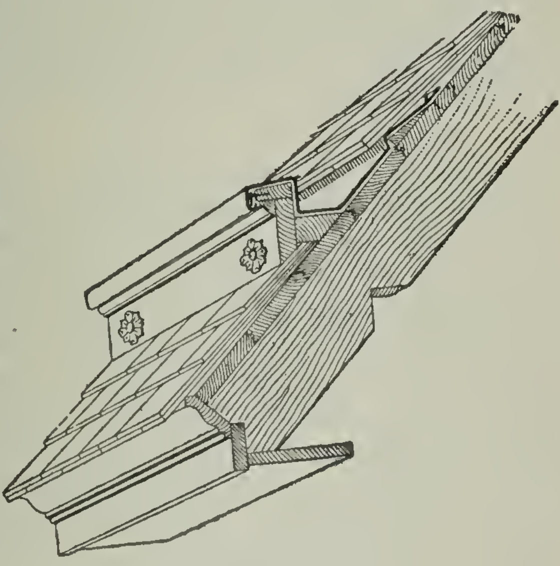


FIG. 6.

Trough gutters of wood, tin, or copper are frequently used, and where securely fastened in place, below the drip line of the roof covering, give good results. Gutters should have a pitch of $\frac{1}{8}$ in. per lineal foot, wherever practicable, so that the bed of the gutter will be well cleansed during a rain fall. Where the pitch is less than stated, it is difficult to flush the dust out of the pockets formed by the "kinking" of the gutter lining.

PLASTERING.

Plastering consists in the application of a plastic material called *mortar*, to the walls and ceilings of a building. The plaster is either laid directly on the face of the wall, or it may be spread over a grille base of wood or metal strips called *lath*, the edges of which are sufficiently separated to allow the mortar to pass through and fold over on the inner face thus forming a *key*, to hold the substance in position.

LATHING.

On brick or stone walls, lathing is usually attached to vertical furring strips, 1 in. thick by 2 in. wide, set at 12″ or 16″ centers. By this means there is a clear air space between the plaster slabs and the wall, thus insuring a continually dry surface, which would otherwise be liable to dampness. In the case of walls in frame buildings, the lath is attached directly to the studs forming the framing of the walls. The ceiling lath may be nailed directly to the under edges of the joists, or attached to cross-furring, similar to that used on the walls, set at right angles to the joists and fixed at 12″ centers. By the latter method better results are obtained, as the warping of the joists does not affect the lath. Lath may be either split or sawed; the former gives a better wall, as there are no cross-grained fibers to reduce the strength, while in the latter such fibers make the lath curl and warp from the absorption of moisture from the mortar; being cheaper, however, sawed lath is generally used. Lath made of pine, spruce, or hemlock, should be straight-grained, well seasoned, free from sap and rot, clear of shakes and large or loose knots, and, to prevent the subsequent discoloration of the plaster, it should be free from live knots and resinous pockets. The regular size of a lath strip is $\frac{1}{4}$ in. × $1\frac{1}{2}$ in. × 4 ft., the length regulating the spacing of the furring strips, studs, and joists. Lath is nailed in place in parallel rows, the edges being kept a full $\frac{1}{4}$ in. apart, to enable the soft plaster to be pressed through and form a key. The ends should not lap,

but be butt-jointed and flush; continuous joints should not occur on one support, but the lathed surface should be divided into panels from 15 in. to 18 in. wide, and the joints be made to break on alternate supports, as shown by the panel *a b c d* in Fig. 1, page 262, otherwise continuous cracks will be liable to disfigure the plaster. The lath is usually attached to joists and studs with cut or wire nails, about $1\frac{1}{8}$ in. in length and having large flat heads, one nail being used at each support. The nails should be galvanized, to prevent the moisture from attacking the iron and causing them to rust, as well as causing large yellow blotches to appear on the surface of the plaster.

There are several metallic substitutes for the wood lathing, such as wire netting, crimped, perforated, and expanded metal, all of which possess much merit, and are preferable to wood.

The carpenter fixes plaster grounds 2 in. wide, shown at *e*, *e*, to the masonry and framework, for the attachment of the joiner work. Plaster casings are also placed around window openings, and false jambs at doorways. For 3-coat work, the plaster grounds on brick or stone walls that are to be coated on the solid wall should be $\frac{5}{8}$ in. thick, and those for lathed surfaces $\frac{7}{8}$ in.; at no point should the surface of the solid wall or that of the lathing approach the face of the grounds nearer than the regulation thickness for the plaster, which will thus be about $\frac{5}{8}$ in.

PLASTERING.

Materials.—The substances which enter into the composition of mortar depend upon the nature of the surface to be coated, the order in which the layers are applied, and the desired finish. For ordinary work they are *lime paste*, *sand*, *hair*, and *plaster of Paris*.

Lime is the product of the calcination or burning of limestone. The material is heated in a kiln until it emits a red glow, thus expelling the carbonic acid and moisture; the residue is quicklime, lumps of which, after being removed from the kiln, are called lime shells. In preparing the mortar, the lime shells are deposited in a wooden slaking

box, and are liberally sprayed with water; they soon begin to swell, crackle, and fall into a powdery mass. This process is called *slaking* and the powdered substance is *slaked* lime; during the process, the lime increases from two to three times in bulk and much heat is given out, which transforms the excess of moisture into steam. Mortar is usually mixed by manual labor, but on extensive works and in cities it is often prepared by mortar mills, a more thorough incorporation of the ingredients and a tougher paste being produced by the machine process.

Sand may be procured from the natural deposits in pits or along river shores. It should be clean; this can be determined by rubbing a moistened quantity of it between the hands; the grains should be sharp and angular, not round and polished. Where the sand is coarse, it should be screened to the desired fineness, by being passed through a sieve. It should be free of salt, otherwise it will attract and retain moisture; this presence can be detected by tasting. Sand is mixed in the mortar for economy, and to check the excessive shrinkage of the lime paste. The sand in the mortar increases its bulk, while sufficient strength is retained, if each grain is well enveloped in a film of the paste.

Hair is employed to bind the paste together and to render it more tenacious. Cattle or goat hair is used for this purpose, but the latter is considered the best. The hair should be long, free from grease and dirt, of sound quality, and beaten up if matted. Owing to the presence of salt in salted hides, hair taken therefrom is undesirable.

Plaster of Paris is obtained from gypsum, by gentle calcination. It is very soluble in water, which renders it unfit for external use, but it is valuable for cornice molds and enrichments, and is also used in several plastic mixtures. The great value of plaster of Paris is that paste made from it rapidly sets and acquires full strength in a few hours. Its volume expands in setting, making it a good material for filling chinks and holes in repair work.

Mixing the Materials.—The composition of the successive coats are generally classified as *coarse stuff*, *fine stuff*, *plasterers' putty*, *gauged stuff*, and *stucco*. For all of them it is essen-

tial that the lime should be thoroughly slaked. In much of the lime used there are more or less overburnt, hard, obstinate nodules which resist the permeation of water, and fail to disintegrate; these must be removed from the lime by screening, otherwise a pitted appearance of the finished work will invariably ensue from the future slaking of the particles.

Coarse stuff, used for the first coat, is composed of from one to two measures of sand to one of slaked lime. The lime paste and hair are well mixed; then, after adding the sand, the mass is worked together with a hoe, until the materials are completely combined. The mixture is then piled in a heap for a week or ten days, to allow it to sour or ferment, the lime expending its heat and becoming effectually slaked. The lime and sand, if mixed while the lime is still hot, produces a much tougher mortar, though some authorities hold that the sand should be added last, after the hair, which, to prevent being charred by hot lime, is always mixed in the mortar after the lime has been cooled. One pound of hair is usually added to every 2 or 3 cu. ft. of mortar, according to requirements, it being essential to add more for ceiling stuff than for walls. The consistency of the prepared mortar should be such that when the paste is made to fold over the edge of the trowel it will hang well together.

Fine stuff is the pure lime which has been slaked to a paste by the addition of a small quantity of water, after which it is further diluted until it is as thin as cream. When the lime held in suspension has subsided, the excess of water is drained off, and the moisture allowed to evaporate until the stuff is sufficiently stiff for use. When desired, a small quantity of white hair is added.

Plasterers' putty, which is always used without hair, is practically fine stuff, but the creamy paste, having been strained through a fine sieve, has become much more velvety.

Gauged stuff consists of about $\frac{3}{4}$ of the foregoing putty and about $\frac{1}{4}$ of plaster of Paris, which causes the mixture to set quickly, so that it must be immediately used, not more than can be applied in 20 or 30 minutes being prepared. An excess of plaster in the mixture will cause the coat to crack. This is used as a finishing coat for walls and ceilings, and

also for running cornices; for the latter work, equal proportions of putty and plaster are used.

Stucco, for interior work, consists of $\frac{2}{3}$ fine stuff and $\frac{1}{3}$ sand, and is used as a finishing coat, the mixture being whipped and reduced, by the addition of water, to a thin paste.

Application.—For 3-coat work, the process of applying and finishing the layers will be described in the order in which they are applied. The coarse stuff is taken in batches from the souring pile, tempered to the proper degree of firmness, shoveled into hods, carried to the rooms, and deposited on the mortar board, as at *f*, Fig. 1. A quantity of mortar is placed on the *hawk g*, by means of the trowel *h*, then slices of the mortar are spread firmly and evenly over the surface of the lathing. The mortar should be tough, hold well together, and soft enough to be pressed between the lath, bulging out behind and forming the key. The thickness of the layer should be fully $\frac{1}{4}$ in.; in cheap work it is often only a skim coat, and it is not unusual to see the lath through it. After the coat has somewhat hardened, it is scratched over diagonally by wooden comb-like blades, as *i*, *i*; from this fact the first layer is often called the *scratch coat*. The grooves fulfil the same function as the spaces between the lath, to allow a good key for the subsequent layer.

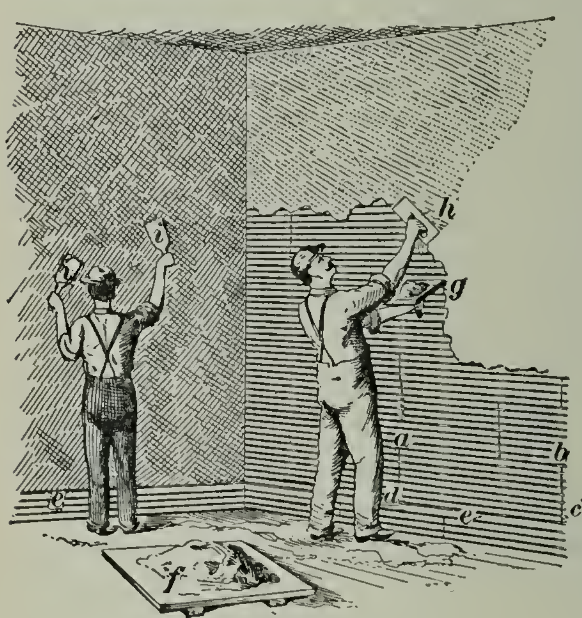


FIG. 1.

The second coat, consisting of fine stuff, to which a little hair is sometimes added, is applied when the scratch coat has

become sufficiently firm to resist pressure; the second layer is called the *brown* or *floated* coat, because its surface is worked by means of board-shaped trowels, called *floats*. It is also known as the *straightening* coat, since all the wall surfaces are straightened and made true. This is effected by first forming a series of plaster bands, called screeds, 5 or 6 in. wide, on the surface to be floated. The surfaces adjacent to the angles are carefully plumbed up from the plaster grounds, but kept about $\frac{1}{8}$ in. back from the face, to allow for the finishing coat. Similar screeds are formed along the ceiling angles; these screeds are made straight, and coincide with those at the opposite angles. Intermediate horizontal and vertical screeds are then formed between the screeds adjacent to the ceiling and the plaster grounds; these are usually placed from 4 to 8 ft. apart, and are gauged to line by means of a straightedge. The screeds thus form a system of framing which has been reduced to a true plane; the panels are then filled in flush with the screeds, and firmly rubbed down with a two-handled float, called the *derby*. The surface is then worked over with a wooden hand float, the coat being firmly compacted by incessant rubbing; when the coat becomes dry during the process, it is moistened with water, applied with a wide brush. A close, firm layer can be obtained only by the thorough, laborious operation of pressing and rubbing the particles of the mortar together. The ceiling surfaces are treated in a similar manner, and the screeds are carefully leveled so as to secure true and level planes. In order to form a key for the subsequent coat, the surfaces are scratched over with a broom.

Where cornices are desired, they are run before the finishing coat is put on; where the molded surfaces do not project more than 2 in., the body may be of coarse stuff, but where the projection is in excess of this, a cradling of brackets and lath, made to conform to the general profile, should be arranged for its support. Cornice molds are made of galvanized iron, or zinc, attached to a wooden back, which in turn is secured to guide and brace strips. Longitudinal strips are attached to the wall either by nails or a layer of plaster of Paris, and on this the mold guide runs. The coarse stuff is made to conform to the approximate profile with a muffled

mold, that is, by forming a layer of plaster of Paris along the edge of the mold, about $\frac{1}{8}$ in. in thickness ; or an extended profile can be cut out of zinc and attached, temporarily, to the mold. When the coarse stuff has been properly profiled, the surface is coated with gauged stuff and carefully worked over with the correct mold, until an exact and perfect finish is obtained. The internal and external angles cannot be finished by means of the molds, but require to be carefully molded and mitered by hand, using steel plates called jointing tools.

There are several kinds of finishing coats, such as *troweled stucco*, *rough sand finish*, *hard-finish white coat*, etc. In all cases the material is applied to the wall in the form of a stiff paste, by means of a steel trowel, and is spread uniformly over the surface to a thickness of about $\frac{1}{8}$ in.

Troweled stucco, consisting of fine stuff and sand, to which a little hair may be added, is thoroughly polished to a glazed finish with a trowel, the surface being kept moist by water applied with a brush.

Rough sand finish can be produced on the stucco by covering the hand float with a piece of carpet or felt, which will cause the sand to raise and present the characteristic sandpaper surface.

Hard-finish white coat consists of gauged stuff, smoothed and polished with the steel trowel; as this material sets rapidly, care must be taken to observe that the second coat is well dried, otherwise the unequal shrinkage will cause hair cracks to occur all over the finishing coat.

A similar finish may be obtained by the use of plasterers' putty, mixed with a small proportion of white sand, and where desired a little white hair may be added; this will give a more durable finish, but it will not set so quickly, and it requires a more thorough working than the former finish.

The space between the plaster grounds and the floor is usually finished with a scratch and a brown coat of plaster, so as to prevent air-currents entering the room from the channels between the furring strips; in cheap work this filling is omitted, the space being covered by the skirting or base.

PLUMBING.

SANITARY MAXIMS.

1. General water-closet accommodation should never be placed in cellar or basement, but should be located where plenty of daylight and ventilation can be obtained, and should open to the outer atmosphere either direct, or by air-shafts at least 3 ft. square.

2. To prevent damp cellars, subsoil drains should be employed where necessary. They must be effectively trapped from sewers or house drains, and some means must be employed to maintain a seal. A check-valve, or back-water trap should be used to prevent a back discharge of sewage into them, should the drains become choked.

3. The arrangement of all drainage or vent pipes should be as direct as possible.

4. If there is a sewer in a street, every building should connect to it separately.

5. Where the soil is *natural*, the house sewer may be of vitrified earthenware pipe, uniformly bedded and jointed with Portland cement and clean sharp sand. This pipe must run straight, and must have a clear bore.

6. If the soil is filled in or *made*, the house sewer must be of extra-heavy cast iron, asphalt-coated; of wrought iron, galvanized, and asphalt-coated; or of brass pipes, to avoid leakage by a settlement of the earth.

7. When it is necessary to run a private sewer to connect with a sewer in another street, it should be laid outside the curb of the street which the buildings face, not across lots where buildings may in future be erected.

8. The main house drains should be run above the cellar floor when possible, and be secured against the cellar walls, supported upon piers built under each joint, or suspended from the cellar ceiling by adjustable hangers.

9. If house drains must be run under the cellar floors they should be laid in straight runs, and clean-outs or inspection

fittings should be placed at each branch or change in direction.

10. All changes in direction should be made with curved pipes or Y branches and $\frac{1}{16}$ or $\frac{1}{8}$ bends.

11. Old sewers should never be employed for new buildings unless first examined and tested by the smoke machine.

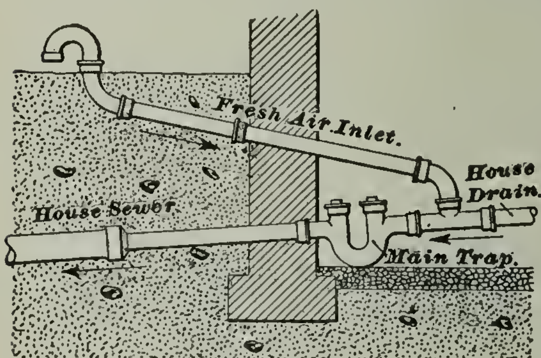


Fig. 1.

12. All house-drainage systems should be disconnected from city sewers by means of a main disconnecting trap, as shown in Fig. 1.

If the sewage from a country building delivers into a sea, a river, or open space, the main drain trap may often be advantageously omitted. A fresh-air inlet must always accompany a main drain trap.

13. Fresh-air inlet orifices must be at least 15 ft. from the nearest window or door, and no cold-air box for a furnace should be so placed as to draw air from them.

14. All vent outlets should discharge at least 2 ft. above the highest part of a roof ridge, coping, or light-shaft, and as far as possible away from the light-shaft and all water tanks.

15. Vent pipes above roofs must be 4 in. in diameter or larger, and no cowls or vent caps should be used.

16. Vent pipes passing up through a low roof, and within 30 ft. of any windows in taller adjoining buildings, should be extended to safe points above the higher roofs.

17. All drain, soil, waste, and vent pipes between the main disconnecting trap and the vent outlets must be clear and unobstructed by traps, check-valves, etc.

18. All house-drainage work should be as accessible as possible, being placed either on the faces of walls or in airshafts. When placed in walls they should be covered by movable pipe boards.

19. Every fixture in a building must be separately trapped close to each fixture, except where a sink and washtubs adjoin each other, in which case the waste pipe from the tubs may join the inlet side of the sink trap below the water seal.

20. All fixture and other such traps in a building must be back-vented by a separate pipe which may deliver into a special back-vent stack at a point about 2 or 3 in. below top of fixture, for tenement or apartment buildings, and at much higher points, if desired, for private-residence work, but in no case at points lower than bottoms of fixtures or bowls.

21. Where lead-waste or back-vent branches connect to cast-iron stacks, the connections must be made with heavy brass ferrules and wiped solder joints; if to wrought-iron or brass stacks, by means of brass-screwed solder nipples provided with a socket to receive the lead pipe and form a flush internal surface. All solder joints in a plumbing system should be "wiped."

22. Special precaution should be taken to secure perfect joints between water-closet traps placed above the floor and the branch soil and vent pipes for same. Brass floor plates should be used for the floor connections. A smoke test is necessary to prove these joints. Back-vent horn or porcelain traps should not be permitted, as they soon break off. The best modern practice is to back-vent the soil-pipe waste close to the floor connection by means of a wiped or screwed joint.

23. Overflow pipes from all fixtures must connect to traps on house side of their seals.

24. All fixture safes should be properly graded to a special waste pipe which must deliver openly at some point, such as a safe-waste sink in the cellar. The outlets of these pipes should be covered with light flap valves.

25. The sediment pipe from the kitchen boilers should not be connected on the outlet side of the sink or other trap.

26. A separate small tank or cistern should be employed to flush every water closet, and in no case should any water closet or urinal be supplied directly from the street pressure pipes when there is any liability of a drawback in the street mains.

27. One water closet, at least, should be allowed for fifteen

inmates of a building. Every story of a tenement should contain at least one water closet.

28. Drinking water should be drawn directly from the street mains. Tank water may be used for washing and bathing purposes.

29. House tanks should be made of wood, and if placed inside the building should be lined with tinned and planished sheet copper.

30. Outside tanks may be circular and made of cedar staves or wrought iron. Overflow from such tanks should discharge on the roof.

31. Overflow pipes from inside tanks may deliver into an eaves gutter if available, or may be trapped and discharge into an open sink. No pipe connecting to a tank should deliver directly into the drainage system.

32. All rain-water leaders, area water boxes, and subsoil drains, must be trapped from the drainage system, and the seals maintained.

33. In all cases where water comes muddy from the mains, a straining filter should be located in the cellar, to filter all water in the building; muddy water clogs boilers, water-backs, and circulation pipes.

34. A special germ-proof filter is a very valuable addition, and should be placed at a convenient point, to supply water for drinking purposes.

35. Steam-exhaust, blow-off, or drip pipes should not deliver directly into a drainage system. Such water should deliver through a deep seal trap, and at a temperature not higher than 100° F.

36. No privy vaults or cesspools for sewage should be permitted in any place where water closets can be connected with a city sewer.

37. All privy vaults and cesspools should be frequently treated with small quantities of disinfectant, and should be cleaned out thoroughly and often.

38. All architects should see that every drainage system, when completed, is tested with smoke under a pressure of at least 1 inch water column, because the sanitary arrangements are seldom perfect when this final test is neglected.

DRAINAGE SYSTEM.

PIPES AND FITTINGS.

Cast-Iron Soil Pipes.—These should be uniform in thickness and homogeneous throughout. They should be tested with water pressure and then coated with asphaltum before being used.

These pipes come in 5′ lengths and are known as *extra heavy.* The maker's name should preferably be cast on each piece. Any pipes lighter than the following should be rejected.

WEIGHT OF CAST-IRON SOIL PIPE.

Nominal Diameter. Inches.	Weight per Foot. Pounds.	Nominal Diameter. Inches.	Weight per Foot. Pounds.
2	5½	7	27
3	9½	8	33½
4	13	10	45
5	17	12	54
6	20		

Cast-iron soil-pipe *fittings* should correspond with the grade of pipes used. They should have easy curves. No sharp 90° bends or **T** branches should be used; only obtuse angle fittings. Fittings are made as staple goods at the following angles: 90°, 45°, 22½°, 11¼°, and are known as quarter, eighth, sixteenth, and thirty-second fittings, respectively.

Cast-iron soil-pipe *joints* are made with picked oakum and molten lead calked solidly home in the sockets; 12 oz. of soft pig lead must be used in each joint for each inch in diameter of the pipe.

Wrought-Iron and Steel Pipes.—When used for drainage purposes these should be stamped with the maker's name. They should be galvanized and conform to the following table:

WEIGHT OF WROUGHT-IRON OR STEEL DRAINAGE PIPE.

Nominal Diameter. Inches.	Thickness of Metal. Inches.	Weight per Foot. Pounds.
1½	.14	2.7
2	.15	3.6
2½	.20	5.7
3	.21	7.5
3½	.22	9.0
4	.23	10.7
4½	.24	12.3
5	.25	14.5
6	.28	18.8
7	.30	23.3
8	.32	28.2
9	.34	33.7
10	.36	40.1
11	.37	45.0
12	.37	49.0

Fittings for vent pipes on wrought-iron or steel pipes may be the ordinary cast or malleable steam and water fittings.

Fittings for waste or *soil pipes* must be the special, extra-heavy cast-iron, recessed and threaded, drainage fittings, with smooth interior waterway and threads tapped, so as to give a uniform grade to branches of not less than ¼ in. per ft.

All *joints* must be screwed joints made up with red lead, and the burr formed in cutting must be carefully reamed out. When the male threads are screwed up tightly, the ends should abut each other in the couplings.

Short nipples on wrought-iron or steel pipe, where the unthreaded pipe is less than 1½ in. long, should be of the thickness and weight known as *extra heavy* or *extra strong.*

Brass Soil, Waste, and Vent Pipes, and Solder Nipples.—These should be thoroughly annealed, seamless drawn, brass tubing of standard iron-pipe gauge. Connections on brass pipe and between brass pipe and traps or iron pipe must not be made with slip joints or couplings. Threaded connections on brass pipe should be tapered and of the same size as iron-pipe threads. The following average thicknesses and weights per lineal foot should be employed:

WEIGHT OF BRASS SOIL, WASTE, AND VENT PIPE.

Nominal Diameter. Inches.	Thickness. Inches.	Weight per Foot. Pounds.
1½	.14	2.8
2	.15	3.8
2½	.20	6.1
3	.21	7.9
3½	.22	9.5
4	.23	11.3
4½	.24	13.1
5	.25	15.4
6	.28	20.0

Brass ferrules should be bell-shaped, extra-heavy cast brass, not less than 4 in. long and 2¼ in. in diameter. The least weight of cast-brass ferrules and solder nipples should be as follows:

WEIGHT OF BRASS FERRULES AND NIPPLES.

Ferrules.			Nipples.		
Inside Diameter.	Weight, Each.		Inside Diameter.	Weight, Each.	
In.	Lb.	Oz.	In.	Lb.	Oz.
			1½	0	8
			2	0	14
2¼	1	0	2½	1	6
3½	1	12	3	2	0
4½	2	8	4	3	8

Particular care should be taken to inspect all cast-brass ferrules before calking them in place, as they are very liable to have sand holes in them, which will cause annoyance in testing the roughing when finished.

Lead Pipes.—The weight of lead pipe should conform to the following table:

WEIGHT OF LEAD SOIL, WASTE, AND VENT PIPE.

Nominal Diameter. Inches.	Weight per Foot. Pounds.	Nominal Diameter. Inches.	Weight per Foot. Pounds.
1¼*	2½	3	6
1½	3	4	8
2	4	4½	8

All lead traps and bends should be of the same weight and thickness as their corresponding pipe branches. This grade is known in commerce as **D**.

SIZES AND GRADE OF SEWERS.

Sizes of Pipes.—House sewer and drain pipes must be at least 4 in. in diameter where water closets discharge into them. Where rain water discharges into them, the house sewer and the house drain up to the leader connections should be in accordance with the following table:

SIZE OF PIPE FOR DRAINAGE.

Diameter.	Drainage Area, Square Feet.	
Inches.	Fall ¼ In. per Ft.	Fall ½ In. per Ft.
6	5,000	7,500
7	6,900	10,300
8	9,100	13,600
9	11,600	17,400

* For flush pipes only.

LEAST SIZES OF SOIL, WASTE, AND VENT PIPE.

Name of Pipe.	Diameter. Inches.
Main and branch soil pipes	4
Main waste pipe	2
Branch waste pipes for kitchen sinks	2
Soil pipe for water closets on 5 or more floors	5
Waste pipe for kitchen sinks on 5 or more floors	3
Bath or sink waste pipe	$1\frac{1}{2}$–2
Basin or urinal waste pipe	$1\frac{1}{4}$–$1\frac{1}{2}$
Pantry-sink waste pipe	$1\frac{1}{2}$
Safe waste pipe	1 –$1\frac{1}{2}$
Water-closet trap	$3\frac{1}{4}$–4
Wash tubs, $1\frac{1}{2}''$ waste pipe and $2''$ trap for set of 2 tubs	$1\frac{1}{2}$–2
Waste pipe for a set of 3 or 4 tubs	2
Main vents and long branches	2
Water-closet vents on 3 or more floors	3
Vent pipe for other fixtures on less than 7 floors	2
Vent pipe for fixtures on 8 stories or less	3
Vent pipe for 9 stories and less than 16	4
Vent pipe for 16 stories and less than 21	5
Vent pipe for 21 stories and over	6
Branch vents for traps larger than 2 in.	2
Branch vents for traps 2 in. or less	$1\frac{1}{2}$

For fixtures other than water closets and slop sinks and for more than 8 stories, vent pipes may be 1 in. smaller than above stated.

All vent pipes that pass out through the roof should be increased one size through and above the roof, to allow for ice accumulations inside. In no case should any of these pipes be less than 4 in. in diameter, except in mild climates. Care should be taken to prevent the use of the old-fashioned cast-iron vent caps. If the open end must be protected, wire baskets may be used.

The fresh-air inlet should be of the same size as the drain, up to 4 in.; for $5''$ and $6''$ drains, it should not be less than 4 in. in diameter; for $7''$ and $8''$ drains, not less than 6 in. in diameter, and for larger drains not less than 8 in. in diameter. The fresh-air inlet orifice should have an area equal to that of the pipe.

Fall for Drain and Waste Pipes.—The fall of a drainage system should be so arranged that the velocity of the flow obtained will be not less than about 275 ft. per min. This velocity can be closely approximated by pitching the pipes as follows:

GRADES FOR DRAIN PIPES.

Diameter. Inches.	Fall.	Diameter. Inches.	Fall.
2	1′ fall in 20′ run	7	1′ fall in 70′ run
3	1′ fall in 30′ run	8	1′ fall in 80′ run
4	1′ fall in 40′ run	9	1′ fall in 90′ run
5	1′ fall in 50′ run	10	1′ fall in 100′ run
6	1′ fall in 60′ run		

DISPOSAL OF SEWAGE.

Sewage from buildings is disposed of chiefly by the following methods: (1) By a connection to the street sewer; (2) by cesspools; (3) by direct or indirect discharge to sea, or river, in close proximity to the buildings. The first plan is always adopted in well-regulated cities, having a sewer system, and the work is usually done under the supervision of city authorities.

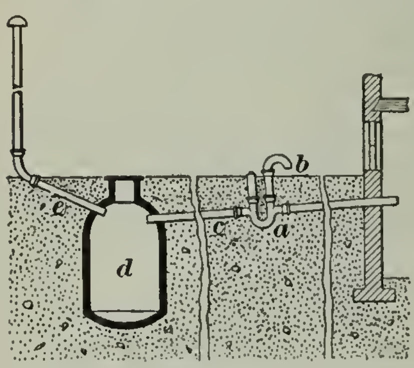


FIG. 2.

Cesspools are commonly used where the first and third methods cannot be employed. They should be built water-tight if within 200 ft. of any buildings or within 100 yd. of any well. Fig. 2 shows common practice in cesspool connections. The main drain from the house is continued through the cellar wall, a trap *a* and fresh-air inlet *b* being placed outside; either a vitrified or a cast-iron sewer pipe *c* connects with the cesspool *d*; and a cesspool vent *e* is run up the trunk of a tree. A tight-fitting manhole cover should be provided for access.

The size of a cesspool must be determined by the approximate amount of discharge. The least size for a 7- or 8-room house is from 6 to 8 ft. in diameter, and from 10 to 12 ft. deep. The following rule is in common use: For a house with 6 rooms or less, make the cesspool 6 ft. in diameter; for a 7-room house, 7 ft.; increase the diameter 6 in. for each additional room up to 10 rooms; then 3 in. for each additional room up to 20; then 1½ in. for each additional room. The general depth is from 10 to 15 ft. The cesspools should be brick-lined, domed over, and, if possible, provided with an overflow.

INSPECTION AND TESTING OF DRAINAGE SYSTEMS.

Drainage systems in all well-regulated cities are inspected and tested twice before being passed by the authorities as perfectly sanitary. These tests are: (1) A test of the *roughing in*, which consists of the iron or brass drains, soil, waste, and vent lines, and sometimes the fixture branches, also, before any pipes are concealed. (2) A test of the entire system when the fixtures are all set, the traps sealed with water, and the work otherwise complete.

The first or roughing test is accomplished by closing all branches and filling the system with water (if the weather permits), allowing the water to stand in the pipes for a certain time, depending on the inspector's judgment. Any leaks can be detected by water flowing from them. In applying this test, particular care must be taken to use plugs in the lower openings, which cannot be blown out by the heavy pressures that occur at these points.

Should the weather be too cold for the water test, the compressed-air test is applied. In this case air is pumped into the system until the pressure is 10 lb. by the gauge, when a valve between the pump and the system is closed. The presence of leaks is made manifest by the gauge indicating a decreasing pressure as the test continues. The location of leaks, however, is difficult unless some pungent volatile oil, as ether or oil of peppermint, is allowed to vaporize within the system and thus cause an odor in the vicinity of the leaks; or, the leaks may be located by the bubbles formed

when a soap-and-water solution is applied to the joints with a brush.

The final test is the more important one. The chief objects are to positively ascertain (*a*) if the system when completed is gas-tight; (*b*) if the traps have perfect seals; (*c*) if every part of the system is trapped that should be trapped; (*d*) if any back-vent pipes are run into hollow partitions, attics, or chimneys. The test was formerly made by vaporizing oil of peppermint in the drainage system, without pressure, trusting to a diffusion of a pungent vapor to indicate any leaks. This form of peppermint test is now abandoned by modern sanitary engineers as untrustworthy, the smoke test being substituted. This is applied by blowing smoke through the system; when the smoke shows at the various vent outlets, they are closed tightly, and the drains are subjected to a smoke pressure of from 1 in. to $1\frac{1}{4}$ in. of water column. This pressure is sufficient to force smoke through the most minute leaks, but is not enough to blow through the seal of a good trap.

The best smoke machine for testing house drains consists of a double-action blower, combined with a smoke-generating chamber furnished with a balanced floating cover. Such a blower will force air through the fire in a steady stream, and a uniform efflux of dense smoke is obtained. The advantage of the floating cover is that it will rise in its water seal when the desired pressure is obtained, and the pressure cannot be increased sufficiently to force the seals of traps, because the excess of smoke will escape to the atmosphere from under the cover. The smoke machine may be applied to the fresh-air inlet; or to one of the vent pipes above the roof—preferably to the latter, as any smoke that escapes while lighting the fuel, which is oily cotton waste, cannot enter the building and thereby spoil the test.

House-drainage systems should be tested once a year, and a report of the sanitary condition should be furnished after each inspection and test. This action is made necessary by the fact that the plumbing is often abused to such an extent as to become dangerous; and settlement of buildings often causes leakage.

PLUMBING FIXTURES.

BATHS.

The most common materials for baths are (*a*) porcelain, or earthenware lined with porcelain enamel; (*b*) cast iron, painted or lined with porcelain enamel; (*c*) tinned sheet-copper lining, inclosed by an iron or steel jacket, commonly called iron-clad baths. Wood-cased tinned copper baths are out of date. Class (*a*) is used in the very finest of work; class (*b*) in plain substantial work; and class (*c*) in cheap work. The two kinds of baths which predominate are the *Roman* shape, which slopes at both ends, and usually has the connections at the back, and the *French* shape, which slopes at one end only, with connections at the foot. French shapes are adapted to corners; Roman, for placing along a wall, away from corners. The following dimensions are taken from a list of baths made by a reputable firm:

Dimensions of Baths.

Dimensions.	Roman Shape.				French Shape.			
	* Porcelain.		† Iron Enameled.		‡ Porcelain.		† Iron Enameled.	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
Length	5	0	4	6	4	6	4	6
Length, including fittings					4	10	4	10
Width outside	2	5	2	5	2	5	2	4
Width, including fittings	2	9	2	9				
Height on legs	2	1	1	11½	2	1	2	0
Depth	1	7	1	7	1	7	1	8
Width of roll rim	0	3		2½	0	3		2½

* A 5′ 6″ bath is the same height, depth, and width of roll rim, but is 1 in. wider.

† The sizes of these baths increase by jumps of 6 in., the other dimensions remaining about the same.

‡ A 5′ bath has same dimensions excepting length; a 5′ 6″ and a 6′ bath are 1 in. wider.

Porcelain baths are variously classed by different makers, but usually alphabetically; class *a* means perfect, without flaw, warp, or twist; class *b*, slightly imperfect, a little warped or rough in the enamel, but hardly perceptible; class *c*, defective, badly warped, cracked, and blistered.

Marble safes for baths are countersunk to a depth of ¼ in. and are 1½ in. thick; they usually project from 3 to 6 in. beyond the outside line of the bath and its trimmings, and should be nearly flush with the floor.

Spray baths and shower baths, furnished with hot and cold water, should be provided with a mixing chamber and a thermometer, the bulb of which must be located in the center of the current. Spray and shower combinations are supplied by makers to fit their baths, but special ones are also furnished, independent of baths. A countersunk marble or slate floor slab 3 ft. 6 in. square, is usually set under a combination, and the bathroom floor is made water-tight. Porcelain receptors, 3 ft. 6 in. square, 9 in. high, 6 in. deep, with 2½ in. roll rim, are preferable, however. About 20 ft. of brass tubing, closely perforated with very fine holes, is sufficient for a good spray. A shower should not be less than 8 in. in diameter. The height from the floor to shower should be about 7 ft. 6 in. The combination should be provided with a 3″ waste pipe, and a 4″ or 5″ flush strainer in the center of floor slab or receptor.

Seat and foot baths vary in sizes and shapes. The following are dimensions of well-designed roll-rim baths:

DIMENSIONS OF SEAT AND FOOT BATHS.

Dimensions.	Seat Bath.		Foot Bath.	
	Ft.	In.	Ft.	In.
Length	2	3	1	10
Length, including fittings	2	8		
Width	2	2	1	7
Width, including fittings			1	11
Height, front	1	0	1	5
Height, back	1	9	1	5
Depth				11
Width of roll rim		2½		2½

They are connected with a hot and cold supply and waste connections, the same as plunge baths.

Rain baths are a kind of shower bath, especially adapted for bathing establishments, and have the advantage over plunge baths for such places, in that they occupy but little floor area, and that they are thoroughly hygienic, as the same water never comes in contact with the body twice.

In all spray, needle, shower, bidet, and rain baths, and shampoos, a mixing chamber should be used. Such a chamber is shown in Fig. 3; cold water, entering through (a), and hot water, through (b), are admitted to the chamber (c) in small jets and thoroughly mixed before passing into the discharge pipe (d), the top of which discharges through the shower, or the shampoo attachment as desired

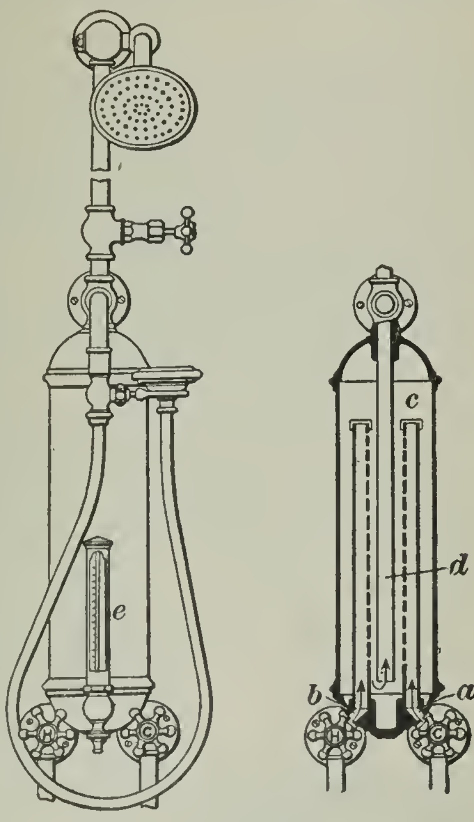


FIG. 3.

A thermometer (e) has its bulb extending into a circuit of mixing water, to indicate the temperature of the mixture. The difference between shower and rain baths is that a shower falls in large drops at low velocity, and the rain comes in minute jets at high velocity.

Sunken baths are simply large pools sunk below the floor level; they are made of wood, brick, or terra cotta, and are lined with sheet lead or copper, or faced inside with enameled tile. The dimensions and capacity depend upon the size of the room. The depth varies from 2 to 4 ft. Water is usually

provided at the end, from a point above the floor level, as from a nozzle attached against the wall. Waste and overflow connections are provided, similar to ordinary baths.

WASH BASINS.

Wash basins are known as round and oval, and may be had with or without overflow attached. Sizes of round bowls are 10, 12, 13, 14, 15, 16, 17, 18, and 20 in. in diameter, measured from the outside of the flange. Oval patterns are 14 in. × 17 in., 15 in. × 19 in., 16 in. × 21 in. The 16″ round, and the 15″ × 19″ oval basins are generally used. Wash basins should be set near windows, in a position convenient to put a mirror over them, so placed as to have the light from both sides.

Marble basin slabs are $1\frac{1}{4}$ in. thick, countersunk on top, and have molded exposed edges. Large slabs should be $1\frac{1}{2}$ in. thick. Basin slabs are right or left hand, according as they set in a corner at the right or left hand as a person faces the basin. Backs are usually 8, 10, or 12 in. high, aprons 5 in. deep, and the height from top of slab to floor is generally 2 ft. $6\frac{1}{2}$ in. Corner basins should be provided with back and end plates; ordinary basins, with back plate only; recess basins, with back and two ends. Safes under basins are the same size as the slabs.

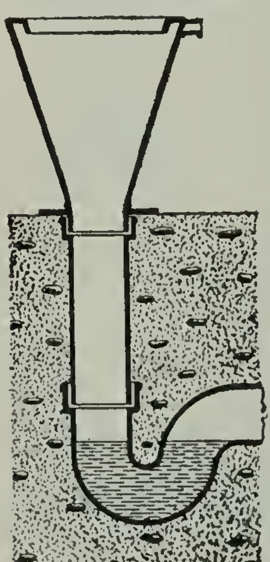


FIG. 4.

WATER CLOSETS.

Pan and Plunger Closets.—These have been condemned by health boards and sanitary authorities for the past 20 years or more, and should never be used; any old ones discovered should be replaced by closets of modern construction.

Hoppers.—Hoppers or washdown closets are designated as *short* or *long* hoppers, according as their traps are above or below the floor. Long hoppers are only used where

there is danger of the trap being frozen, in which case the traps are placed below frost level. A long hopper is shown in Fig. 4, while Fig. 5 illustrates a short hopper. They can be

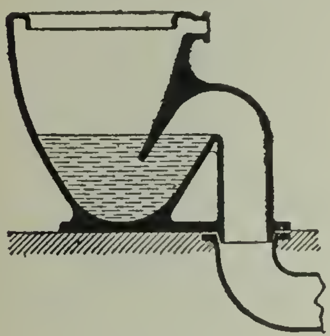


FIG. 5.

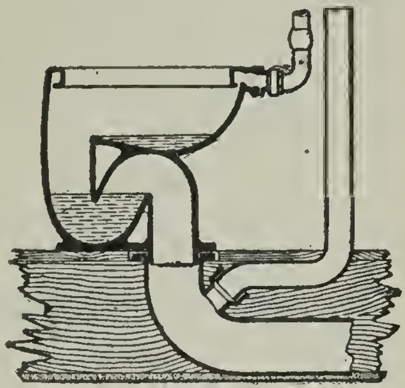


FIG. 6.

had in porcelain, glazed earthenware, or cast iron painted or enameled. Short hoppers are fitted with a flushing tank overhead; long hoppers are usually fitted with a valve below frost level.

Washout Closets.—They consist of a basin and trap, both above the floor. They differ from hopper closets in that the water in the basin is separate from that in the trap, as shown in Fig. 6. They are generally used on good common work, and are thoroughly sanitary; but, being somewhat noisy, are not so desirable as siphon closets for dwellings.

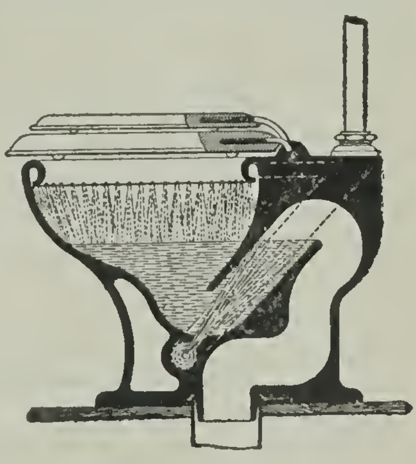


FIG. 7.

Siphon Closets.—They have their contents removed by siphonage through a long crooked outlet, the water in the basin being employed as a trap. They are almost noiseless in operation. There are many kinds of these closets on the market but the most reliable are the simple siphon-jet

arrangements with flushing rim, as shown in accompanying figure. Those having a low-down tank are the most silent in action. Pneumatic siphon-jet closets are too complicated to be reliable. Fig. 7 shows the closet in action; the dotted lines show the water channels for the flush.

The dimensions of closets vary considerably; the following, however, is good practice:

Width of bowl over all	13 in.
Height from seat to floor	17 in.
Depth from wall to front of seat	23 in.

The distances from the center of the outlet opening to the walls, etc.—or the "roughing-in" dimensions, as they are called—vary with nearly every closet.

Latrines.—Latrines are used chiefly for prisons, factories, etc., and are set up in ranges of two or more, partitions being placed between each latrine, about 24 in. apart. The waste-pipe section is usually 5 or 6 in. in diameter, and the flush pipe 3 or 4 in. They are flushed by a large tank, located about 6 ft. above the seat, the flush pipe being connected to the bottom of the latrines.

Closet Ranges.—Closet ranges, used in schools, factories, etc., are merely large troughs with one outlet and a flushing arrangement. They should be simple and have no mechanical parts to get out of order. There are many different kinds, but the automatic-supply range is probably the best. The combinations are of 3 lengths, 24, 27, and 30 in. between partitions; height from floor to top of seat, 1 ft. 6 in.; height from floor to top of iron partition, 5 ft. 10 in.; depth of partition, 2 ft. 2 in.; width of range, from front to back, 1 ft. 7 in. They can be had painted or enameled. If a hot chimney is near, it is advisable to use local vent-closet ranges, and in such case allow about 15 in. extra length for a ventilating extension.

Closet Seats.—Closet seats should be made of hard wood, and the grain arranged so that the seat will not warp, sliver, or fall to pieces. Quartered oak, in two or three layers crossed, or in one piece with dowels or cross-strips, seems to be the best material. The seat should be secured to the porcelain bowl. The hole should taper from back to front,

and have the shape and dimensions shown in Fig. 8. The upper surface of the seat should be properly countersunk.

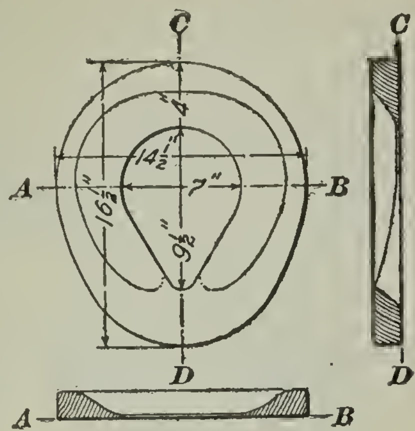


FIG. 8.

Seat Vents.—Many closets are provided with horns above the water-line in the bowl, for the purpose of ventilating the bowl. These are of no use, however, unless a strong, positive draft is constantly maintained in the vent lines. The size of vent pipe is preferably 3 in. for each closet, and not less than 2 in.

Two or three closets may local vent into a 4″ pipe, the size of the pipe increasing with the number of closets connecting to it. All closets having horns attached to them for back-venting traps should be discarded, as these horns easily break off. All connections between metal pipes and porcelain should be bolted flange joints, without horns.

Floor Connections.—The ordinary brass-bolted floor flange makes a good connection, but if it is not perfect there is no means of knowing the fact. One of the best floor connections for a closet is shown in Fig. 9. This is a water-sealed floor connection. The pipe a is continued $1\frac{1}{4}$ in. above the finished floor, the end being rounded and free from burrs. The floor is countersunk to receive a supporting flange b which is attached to the pipe. A brass flange c compresses the rubber gasket d against the porcelain when the bolts e are drawn up. An annular space is thus formed around the neck of the pipe a, which fills with water at the first operation of the closet, thus seal-

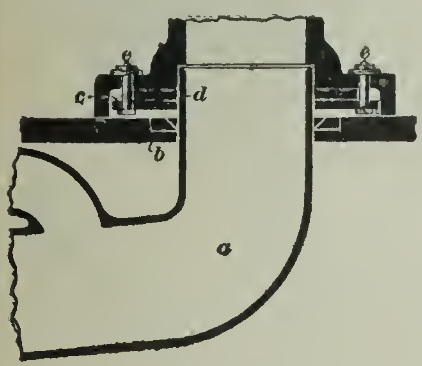


FIG. 9.

ing the connection. If the connection leaks, this water will run out on the floor; if it does not, gas cannot escape.

Closet Cisterns.—There are a variety of kinds of closet cisterns on the market, some being simple and others complicated. In choosing a closet tank, (1) select for flushing qualities; (2) quietness in action; and (3) simplicity of construction.

Fig. 10 shows a *plain valve* cistern for wash-down closets and hoppers; its dimensions are about 23 in. × 12 in. × 10 in. It is provided with a ball-cock *a* and an outlet valve *b* which is operated by a lever *c* bolted to a cross-bar *d*, the lever being worked by a chain pull. The tube *g* forms an overflow which discharges into the flush pipe *e*. A deafening pipe *f* deadens the noise of the incoming water. The volume of flush from this tank is irregular, depending on the time the valve *b* is held up.

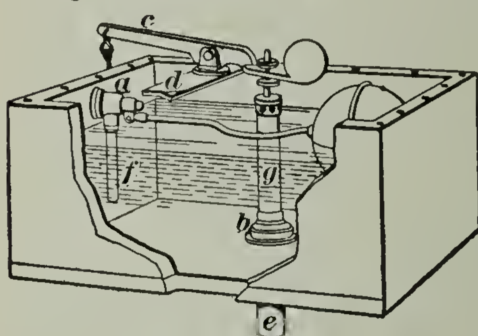


Fig. 10.

A better arrangement is shown in Fig. 11. This is a *siphon* cistern particularly adapted for wash-outs as well as wash-downs and hoppers; its dimensions are about 19 in. × 9 in. × 10 in. A momentary retention of the pull opens the valve *a* and starts the siphon, formed by the shell *b* suspended over, and attached to, an inner standing tube, which is secured to the valve *a*. A *refill* to the bowl is obtained by a slot in the lower end of the siphon tube *b* which causes the siphon to break gradually.

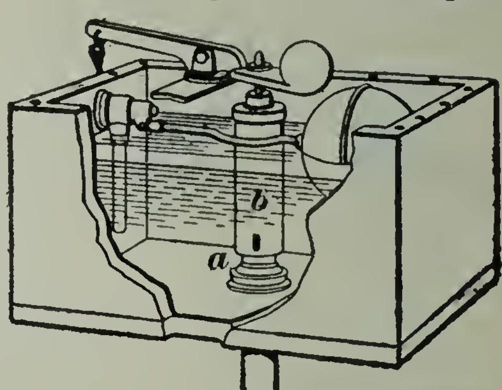


Fig. 11.

An *after-wash* cistern, shown in Fig. 12, is suitable for seat action. The lever is attached to the seat in such a manner that when the seat is depressed the valve *a* is closed, and the valve *b* opens, causing a flow from chamber *c* into chamber *d*. When the seat is released *a* opens, *b* closes, and the closet is flushed.

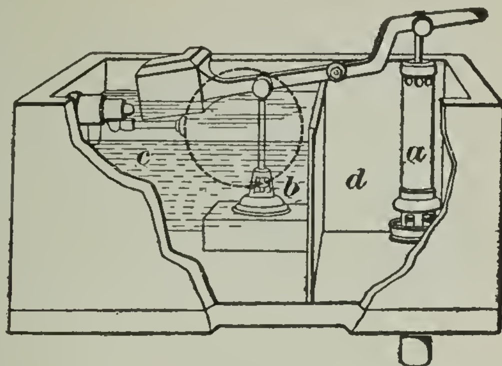


Fig. 12.

A refill *float-valve* cistern especially suitable for siphon-jet closets, and wash-out closets requiring a refill to bowl, is shown in Fig. 13. When the float *a* is raised it remains buoyed up until sufficient water has passed through the closet, when it returns gradually to its seat. The pipe *b* serves as an overflow and at the same time gives an abundant refill to the bowl.

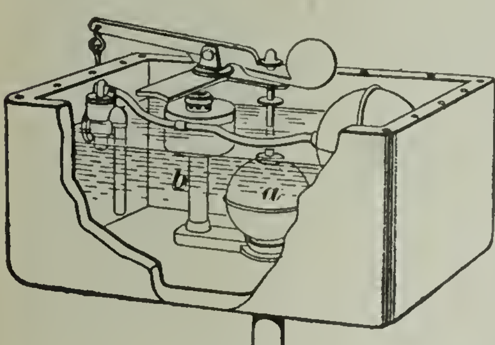


Fig. 13.

These cisterns are remarkably quiet in action. They are made in two sizes. Cisterns with valves away from the edges are preferable, for the wood is liable to warp and cause the lock-nuts to cut the copper.

Water-closet floor slabs are about 27 in. square, and countersunk around the closet. When ordered in a closet combination the hole is cut, and the countersinking done, by the manufacturer. They can be had in Italian or Tennessee marble, and slate. These slabs are sent with unpolished edges and corners, unless otherwise ordered. When the slabs are to be drilled for pipes, a diagram should accompany the order, giving exact distances to centers of openings.

URINALS.

Urinal ranges are lipped troughs with partitions set 2 ft. apart. They are most satisfactory when flushed by an automatic-siphon tank which discharges through a large jet at the upper end and a spray tube at the back. The tank should be at least 4 ft. above the spray tube. The outlet to trough should be arranged with a siphon which will automatically discharge contents when the supply tank discharges. The period of automatic flushes vary with the water supply; good flushes are obtained if the interval is from 5 to 10 min.

Urinal ranges are made of cast iron, either plain, painted, or, preferably, enameled. The usual dimensions of a urinal range are about as follows: Height of partition, 5 ft. 8 in.; width of partition, about 1 ft. 6 in.; width of urinal, from back to front of lip, 11 in.; depth of trough, 6 in.; regular height of lip, 2 ft.; the height for children is 1 ft. 2 in.

Individual urinals are made of porcelain and are provided with at least two openings, one for the flush and the other for the discharge. The best class have perforated flushing rims, and overflow openings inside. They are known as flat or corner urinals. The best forms are those in which the trap is combined with the bowl, and arranged to be connected without any metal being exposed. The connection between the porcelain and the metal is usually water-sealed, which is advantageous. The waste pipe is provided with a flange and bolt for making a perfect junction with the earthenware. When a flushing tank is used, the combination is simple, efficient, and hygienic.

Individual urinals are set in stalls, the height of which stall should be at least 5 ft. 6 in.; width inside, 2 ft.; length of partition, 2 ft. 4 in.; depth of middle partition, 1 ft. 8 in. Middle partitions stand on nickel plated brass legs about 10 in. high. The size of urinal cisterns should be, for 2 urinals, a 2-gal. cistern; 3 urinals, a 3-gal. cistern, etc.

SINKS.

Sinks are generally classified as kitchen, pantry, slop, and stable sinks, and are made of different materials and in numerous sizes and shapes.

Kitchen sinks are generally rectangular in plan, and are not provided with plug and chain, or overflow openings. Special kitchen sinks are furnished to order with overflow attachments and plugs.

SIZES OF CAST-IRON KITCHEN SINKS.

(*Depth inside; other dimensions outside.*)

Length. Inches.	Width. Inches.	Depth. Inches.	Length. Inches.	Width. Inches.	Depth. Inches.
16½	12½	5	30	20	6
18	12	6	32½	18	6
16	16	6	32½	21	6
22	14	6	36	18	6
23	15	6	36	21½	6
25½	15½	6	38	20	6
20	12½	6	42	22	6
20	14	6	48	20	6
24	14	6	48	23	6
24½	16	6	24	14	8
24	18	6	30	24	8
25½	17½	6	50	24	6½
27	15	6	50	26	6½
24	20	6	62	22	8
28	17	6	76	22	7
28	20	6	56	32	9
30	16	6	60	28	10
30	18	6	78	28	10

All sinks should be fitted up open, that is, no woodwork of any description in the form of boxings should be allowed near them, for these boxings become moist and foul, and make breeding places for cockroaches and other vermin. If possible, the walls against which sinks are set should be of glazed tile or other material of a non-porous character.

Sloping drain boards should be provided at every sink. Ash or oak from 1¼ to 2 inches thick are well adapted for drain boards. Sinks that are not cast with sloping bottoms should be set so that the bottom will have a fall towards the strainer. The faucets should be located, if possible, at the end opposite the strainer.

SIZES OF COPPER PANTRY SINKS.

Length. Inches.	Width. Inches.	Depth. Inches.
12	18	5–6
12	20	5–6
14	16	5–6
14	20	5–6
14	24	5–6
16	24	5–6
16	30	5–6
18	30	5–6

SIZES OF PORCELAIN SINKS.

Length. Inches.	Width. Inches.	Depth. Inches.
36	23	7
42	24	7
48	24	7
28	18	9
30	20	9

SIZES OF CAST-IRON SLOP SINKS.

Length. Inches.	Width. Inches.	Depth. Inches.
16	16	10
20	14	12
20	16	12
24	20	12
30	20	12
36	18	12
36	21	12
23	15	15
36	21	16
48	20	12
48	20	17
60	20	12

SIZES OF EARTHENWARE PANTRY SINKS.

Length. Inches.	Width. Inches.	Depth. Inches.
20	14	$4\frac{1}{2}$
23	16	$5\frac{1}{2}$
25	17	$5\frac{1}{2}$

Porcelain sinks can be had with a plain top or roll rim. Copper pantry sinks are made in either square or oval patterns; the former has a flat, and the latter, a round bottom. Sizes for both patterns are given in the table.

Pantry and kitchen sinks should be set 2 ft. 6 in. or 2 ft. 7 in. from the floor to the top of the cap. Slop sinks can be had with or without overflow and plug. These sinks should be set at such a height that the rim will be not more than 24 in. from the floor.

A sink should be located near a window for light, near the pantry or dining room for convenience, and away from the stove for comfort.

LAUNDRY TUBS.

Laundry tubs, generally speaking, are made of slate, cement, soapstone, glazed earthenware, or solid porcelain. Wood, cast iron or sheet steel are not suitable materials for wash tubs. Tubs used in tenement and apartment houses should be provided with overflows. The height of wash tubs from floor to top of rim is from 32 to 36 in. The wringer should be set on the right-hand tub.

The following tables give the average sizes of slate and cement tubs:

Slate Tubs.				Cement Tubs.			
No. Parts.	In. Long.	In. Wide.	In. Deep.	No. Parts.	In. Long.	In. Wide.	In. Deep.
1	24	24	16	2	48	21 or 24	16
2	48	21	16	2	53	24	16
2	54	24	16	2	60	24	16
3	78	24	16	3	72	21 or 24	16
				3	80	24	16
				3	90	24	16

Earthenware and *porcelain* tubs come separately, and are connected up singly or in sets of 2, 3, or 4, as required. They are made in two sizes, Nos. 1 and 2, according to the dimensions shown in the following table:

Dimensions.	No. 1.		No. 2.	
	Ft.	In.	Ft.	In.
Length for each tub	2	0	2	$7\frac{1}{2}$
Length required for 2 tubs	4	1	5	4
Length required for 3 tubs	6	2	8	0
Length required for 4 tubs	8	3	10	9
Width from front to back	2	$1\frac{1}{2}$	2	$1\frac{1}{8}$
Depth inside	1	3	1	3

WATER SUPPLY AND DISTRIBUTION.

METHODS OF SUPPLY.

The source of supply of water to a building will depend upon prevailing conditions and the location of the building. City buildings are usually supplied from city mains, while country buildings are supplied from wells, lakes, and streams, by means of pumps, hydraulic rams, etc.

Street Service.—House pipes should connect to the mains by *corporation stops.* A stop and waste should always be placed under the sidewalk at the curb, and also a separate stop and waste upon the service pipe just inside the cellar wall.

If the street pressure is great enough to force water to the top floor of a building, all fixtures are usually supplied with both hot and cold water, by street pressure. If the pressure is too low, or the supply intermittent, a tank is placed in the attic to supply the building. If the pressure is too high, it is customary to apply a pressure regulator in the cellar.

The sizes of street service pipes depend chiefly upon the street pressure and the size of building to be supplied. The following is common practice:

SIZES OF STREET SERVICE PIPES.

Class of Building.	Size of Pipe. Inches.
Single dwellings, two or three stories high	$\frac{1}{2}$ or $\frac{3}{4}$
Larger dwellings	1 or $1\frac{1}{4}$
Tenement buildings and apartment houses	$1\frac{1}{2}$ or 2
Hotels and factories	2 and up

These pipes should be increased one size if pressure is low.

Pumps.—The amount of water raised by single-acting pumps is estimated by multiplying the number of strokes which the piston travels in one direction per minute by the volume displaced or traversed by the piston in a single stroke, the supposition being that the water flows into the pump barrel

only when the piston ascends. It has been found, however, that the column of water does not cease flowing when the piston descends, and that the amount of water delivered is greater than usually supposed; in some cases, it is nearly double the theoretical amount.

A column of water 34 ft. high is balanced by the pressure of the atmosphere, but in practice it requires a very good pump to *draw* to a height of 28 ft.

Pumping Hot Water.—The height to which hot water can be raised by suction is much less than that of cold water, the height varying with the temperature. This is due to the increased pressure of the vapor. Where possible, the hot water should flow into the pump by gravity. The following table gives the maximum vertical heights of suction pipes for different temperatures:

Absolute Pressure of Vapor. Lb. per Sq. In.	Vacuum. Inches of Mercury.	Temperature. Degrees, Fahr.	Maximum Height of Suction. Feet.
1	27.88	101.4	31.6
2	25.85	126.2	29.3
3	23.81	144.7	27.0
4	21.77	153.3	24.7
5	19.74	162.5	22.4
6	17.70	170.3	20.1
7	15.66	177.0	17.8
8	13.63	183.0	15.5
9	11.59	188.4	13.2
10	9.55	193.2	10.9
11	7.51	197.6	8.5
12	5.48	201.9	6.2
13	3.44	205.8	3.9
14	1.40	209.6	1.6

The Hydraulic Ram.—This machine is employed to raise water to a point higher than the source of supply; it is chiefly used where a large flow of water with a low fall is obtainable, and raises part of the water which operates it. The efficiency varies with the ratio of the rise of the discharge to the fall of the drive pipe, about as follows:

Ratio of lift to fall,	4,	6,	8,	10,	12,	14,	16,	18,	20,	22,	24,	26.
Per cent. efficiency,	72,	61,	52,	44,	37,	31,	25,	19,	14,	9,	4,	0.

To obtain the highest efficiency with any fall, the dash valve should be adjusted to close at the instant the water in the drive pipe has attained its maximum velocity.

A ram having a discharge pipe 80 or 100 ft. long will deliver about $\frac{1}{7}$ the quantity supplied to a height about five times the fall; or $\frac{1}{14}$ the quantity supplied to a height of ten times the fall.

If the pipes are lead, the drive pipe should be of the **A** grade, for diameters up to 2 in., and cast or wrought iron for greater diameters. The discharge pipe, if lead, should be of the **B** grade for rises of 50 ft. or less, and of the **A** grade for rises between 50 and 100 ft. For falls greater than 10 ft., or rises of more than 100 ft., the pipe must be heavier than just given. The length of drive pipe should be from 25 to 50 ft. If the discharge pipe is very long (say $\frac{1}{4}$ mile) a larger size than given in the table should be used. With a given supply of water under a great fall, the ram need not be as large as for the same quantity of water under a less fall. When large quantities of water are to be raised, it is better to increase the number of rams, in preference to having one of very large capacity. Several rams may be set so as to deliver into one discharge pipe, each having a separate drive pipe.

SIZES OF PIPE FOR RAMS.

Water Supply to Ram. Gal. per Min.	Size of Pipe.	
	Drive. In.	Discharge. In.
$\frac{3}{4}$ – 2	$\frac{3}{4}$	$\frac{3}{8}$
$1\frac{1}{2}$ – 4	1	$\frac{1}{2}$
3 – 7	$1\frac{1}{4}$	$\frac{1}{2}$
6 – 14	2	$\frac{3}{4}$
12 – 25	$2\frac{1}{2}$	1
20 – 40	$2\frac{3}{4}$	$1\frac{1}{4}$
25 – 75	4	2

Cisterns.—These are used to store rain water underground, for use in country buildings. For an ordinary house with 8 rooms or less, located in a climate where the rainfall is not less than 30 in. per annum, and where very long droughts do not occur, a brick cistern 5 ft. in diameter and 7 ft. deep will be large enough for a family of 10 people. Larger buildings should be provided with two or more cisterns.

Cistern filters are essential in all cases. Fig. 14 shows an excellent and simple form, which may be built a few feet away from the cistern, and connected to it by the pipe *f*. The filter well is built of brick, laid in 1-to-1 Portland cement mortar, and is divided into two compartments by a partition slab *a* of slate or flagstone. The bottom is inclined so that the sediment will collect at *d*. The chamber *B* has a perforated bottom *b*, upon which is placed a course of gravel, then clean sand, and is topped with gravel nearly up to the level of the discharge pipe *f*. Rain water enters *A* through the pipe *c*, and deposits any mud that it may contain, at *d*. Any overflow in *A* is discharged through pipe *e*. The water flows upwards through the sand in chamber *B*, which clarifies it. The filter may be easily cleaned by stopping up *f*, pouring water into *B*, and pumping out the mud and dirty water from *A*. Renewal of the filtering material is thus seldom necessary.

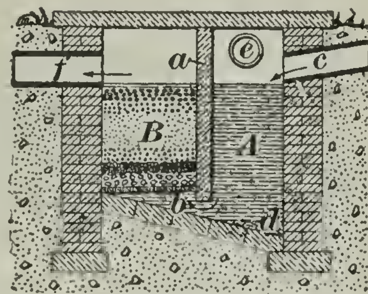


FIG. 14.

DISTRIBUTION.

SIZES OF WATER PIPES IN BUILDING.

Supply Branches.	Low Pressure. Inches.	High Pressure. Inches.
To bath cocks	$\frac{3}{4}$–1	$\frac{1}{2}$–$\frac{3}{4}$
To basin cocks	$\frac{1}{2}$	$\frac{3}{8}$–$\frac{1}{2}$
To water-closet flush tank	$\frac{1}{2}$	$\frac{1}{2}$
To water-closet flush valve	1–$1\frac{1}{4}$	$\frac{3}{4}$–1
To water-closet flush pipes	$1\frac{1}{4}$–$1\frac{1}{2}$	
To sitz or foot baths	$\frac{1}{2}$–$\frac{3}{4}$	$\frac{1}{2}$
To kitchen sinks	$\frac{5}{8}$–$\frac{3}{4}$	$\frac{1}{2}$–$\frac{5}{8}$
To pantry sinks	$\frac{1}{2}$	$\frac{3}{8}$–$\frac{1}{2}$
To slop sinks	$\frac{5}{8}$–$\frac{3}{4}$	$\frac{1}{2}$–$\frac{5}{8}$
To urinals	$\frac{5}{8}$–$\frac{3}{4}$	$\frac{1}{2}$–$\frac{5}{8}$

Kitchen Boilers.—Iron boilers, or hot-water storage tanks, should be galvanized both outside and inside, particularly inside. These boilers are commonly made of mild steel, and are not so durable as the old-time wrought-iron boilers. Many of the poorer grades become pitted very rapidly, and are not to be recommended for first-class work. The longitudinal seams are either *single* or *double* riveted; when double riveted, the rivets should be *staggered.*

Copper range boilers are in every case to be preferred, if properly coated inside with block tin. They are classed as *light, heavy* and *extra heavy,* the latter being tested to 150 lb. water pressure. The best forms of copper boilers are those which are reinforced inside by stiffeners or braces so that they will not collapse when a partial vacuum is formed within them.

Ordinary steel or iron boilers are tested to 150 lb. water pressure, and extra heavy ones to 250 lb. pressure. The latter should always be used when the street pressure is more than 40 lb. by the gauge, or when a water hammer may at any time come upon the plumbing system.

STANDARD SIZES OF GALVANIZED BOILERS.

Capacity. Gal.	Length. Ft.	Diameter In.	Capacity. Gal.	Length. Ft.	Diameter. In.
18	3	12	48	6	14
21	3½	12	52	5	16
24	4	12	53	4	18
24	3	14	63	6	16
27	4½	12	66	5	18
28	3½	14	79	6	18
30	5	12	82	5	20
32	4	14	98	6	20
35	5	13	100	5	22
36	6	12	120	6	22
36	4½	14	120	5	24
40	5	14	144	6	24
42	4	16	168	7	24
47	4½	16	182	8	24

The size of boiler which should be employed for any particular work depends chiefly upon existing conditions, such,

for example, as the water supply and the nature of the building. A safe rule is to allow a 35- or 40-gal. boiler for a building having one bathroom, and to add 30 gal. additional capacity for every extra bathroom. The size can only be computed by first ascertaining the maximum quantity of hot water which will be drawn off in a given time, and the nature of the heating agents which warm the water.

The size of the waterback is another item which cannot be calculated, because it is based on the size of the boiler or

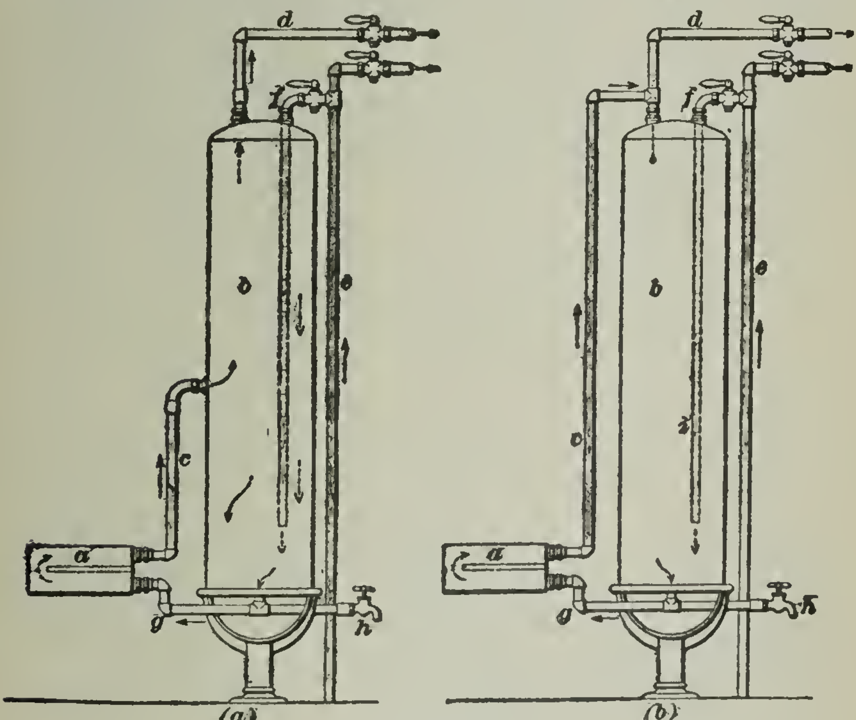


FIG. 15.

the quantity of water to be heated in a given time. In practice it is found that about 100 sq. in. of waterback heating surface in actual contact with the fire is sufficient to give good results with a 40-gal. boiler if water is plentiful, and with a 50-gal. boiler if water is scarce.

Boiler Connections.—These are made in different ways, but the most common and reliable method is shown at (*a*) in Fig. 15. The cold supply pipe *e* has a branch *f* taken off, to

supply the boiler. The return pipe *g* furnishes a supply to the waterback *a*, and the sediment cock *h* is used to empty the boiler when necessary. The hot water enters the boiler through the flow pipe *c*, and rising to the top, is conveyed to the fixtures through *d*. The only objection to this arrangement is that it requires a long time for the water in the boiler to become hot, because the hot water continually mixes with the cold. To overcome this trouble, *c* is often connected to *d* over the boiler, as shown in (*b*). But the latter method is also objectionable, in that circulation between the range and the boiler will cease when the service pipe is shut off, because the hot water will siphon down to the vent hole in the top of the inner tube. The waterback will then blow steam through *c* and *d*.

PLUMBERS' TABLES.

FLUXES.

Flux.	Used With.	Metals to be Joined.
Resin.	Copper bit or blowpipe.	Lead, tin, copper, brass, and tinned metals.
Tallow, unsalted.	Blowpipe or wiping process.	Lead, tin, or tinned metals.
Sal ammoniac.	Copper bit or blowpipe.	Copper, brass, and iron.
Muriatic acid.	Copper bit.	Dirty zinc.
Chloride of zinc.	Copper bit or blowpipe.	Clean zinc, copper, brass, tin, and tinned metals.
Resin and sweet oil.	Copper bit or blowpipe.	Lead and tin tubes.
Borax.	Blowpipe.	Iron, steel, copper, and brass.

SOLDERS.

Variety.	Hard.			Soft.			Fusing Point.
	Zinc.	Copper.	Silver.	Tin.	Lead.	Bismuth.	
Spelter, hardest	1	2					700°
Spelter, hard	2	3					
Spelter, soft	1	1					550°
Spelter, fine	2	2	¼				
Silver, hard		1	4				
Silver, medium		1	3				
Silver, soft		1	2				
Plumbers', coarse				1	3		480°
Plumbers', ordinary				1	2		440°
Plumbers', fine				2	3		400°
Tinners'				1	1		370°
For tin pipe				3	2		330°
For tin pipe				4	4	1	

WEIGHT PER FOOT OF LEAD PIPE AND TIN-LINED LEAD PIPE.

Inside Diam.	*A A A* Brooklyn		*A A* Extra Strong.		*A* Strong.		*B* Medium.		*C* Light.		*D* Extra Light.	
In.	Lb.	Oz.	Lb.	Oz.	Lb.	Oz.	Lb.	Oz.	Lb.	Oz.	Lb.	Oz.
⅜	1	12	1	8	1	4	1	0	0	12	0	10
7/16							1	0	0	13		
½	3	0	2	0	1	12	1	4	1	0	0	12
⅝	3	8	2	12	2	8	2	0	1	8	1	0
¾	4	12	3	8	3	0	2	4	1	12	1	4
1	6	0	4	12	4	0	3	4	2	8	2	0
1¼	6	12	5	12	4	12	3	12	3	0	2	8
1½	8	8	7	8	6	8	5	0	4	4	3	8
1¾	10	0	8	8	7	0	6	0	5	0	4	0
2	11	12	9	0	8	0	7	0	6	0	4	12

WEIGHT OF SHEET ZINC, COPPER, AND LEAD.

Zinc.		Copper.		Lead.	
Thickness. Inches.	Weight, per Sq. Ft. Ounces.	Thickness. Inches.	Weight, per Sq. Ft. Ounces.	Thickness. Inches.	Weight, per Sq. Ft. Pounds.
.031	10	.013	10	$\frac{1}{20}$	3
.046	12	.016	12	$\frac{1}{15}$	4
.053	14	.019	14	$\frac{1}{12}$	5
.061	16	.022	16	$\frac{1}{10}$	6
.069	18	.025	18	$\frac{1}{8}$	$7\frac{1}{2}$
.076	20	.029	20	$\frac{2}{15}$	8

WEIGHT PER FOOT OF LEAD TUBING AND WASTE PIPE.

Tubing.		Waste Pipe.			
Diameter Inches.	Weight Ounces.	Diameter Inches.	Weight Pounds.	Diameter Inches.	Weight Pounds.
$\frac{1}{16}$	$\frac{3}{4}$	$1\frac{1}{2}$	2	4	5, 6, 8
$\frac{1}{8}$	$1\frac{1}{4}$	2	3, 4	$4\frac{1}{2}$	8, 10
$\frac{5}{32}$	$2\frac{1}{4}$	$2\frac{1}{2}$	4, 6	5	8, 10, 12
$\frac{1}{4}$	5, 6, 8, 13	3	$4\frac{1}{2}$, 5	6	12, up.

WEIGHT OF BRASS TUBING.

Nominal Diameter. Inches.	Weight per Lineal Foot. Pounds.	Nominal Diameter. Inches.	Weight per Lineal Foot. Pounds.
$\frac{1}{8}$	.25	2	4.00
$\frac{1}{4}$	.43	$2\frac{1}{2}$	5.75
$\frac{3}{8}$	.62	3	8.30
$\frac{1}{2}$	.90	$3\frac{1}{2}$	10.90
$\frac{3}{4}$	1.25	4	12.70
1	1.70	$4\frac{1}{2}$	13.90
$1\frac{1}{4}$	2.50	5	15.75
$1\frac{1}{2}$	3.00	6	20.60

WEIGHT OF SHEET IRON.

Number of Gauge.	Thickness. Inches.	Black Iron. Weight per Sq. Ft. Pounds.	Number of Gauge.	Thickness. Inches.	Black Iron. Weight per Sq. Ft. Pounds.	Galvanized Iron. Weight per Sq. Ft. Pounds.
1	.300	12.0	16	.065	2.6	3.0
2	.284	11.4	17	.058	2.3	2.7
3	.259	10.4	18	.049	2.0	2.3
4	.238	9.5	19	.042	1.7	2.1
5	.220	8.8	20	.035	1.4	1.7
6	.203	8.1	21	.032	1.3	1.5
7	.180	7.2	22	.028	1.1	1.3
8	.165	6.6	23	.025	1.0	1.2
9	.148	5.9	24	.022	0.9	1.1
10	.134	5.4	25	.020	0.8	1.0
11	.120	4.8	26	.018	0.7	1.0
12	.109	4.4	27	.016	0.6	0.9
13	.095	3.8	28	.014	0.6	0.7
14	.083	3.3	29	.013	0.5	0.7
15	.072	2.9	30	.012	0.5	0.6

SPACING OF LEAD PIPE TACKS.

Size of Pipe. Inches.	Vertical Pipe.		Horizontal Pipe.	
	Hot. Inches.	Cold. Inches.	Hot. Inches.	Cold. Inches.
$\frac{3}{8}$	18	24	12	16
$\frac{1}{2}$	19	25	14	17
$\frac{5}{8}$	20	26	15	18
$\frac{3}{4}$	21	27	16	19
1	22	28	17	20
$1\frac{1}{4}$	23	29	18	21
$1\frac{1}{2}$	24	30	18	22

Tacks are spaced closer on hot than on cold pipes, as lead is much more liable to sag when heated.

LENGTH OF WIPE JOINTS FOR LEAD PIPE.

Diameter of Pipe. Inches.	Length of Joint. Inches.	Diameter of Pipe. Inches.	Length of Joint. Inches.	Diameter of Pipe. Inches.	Length of Joint. Inches.
$\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{1}{4}$ water	3	2 waste	$2\frac{1}{4}$
$\frac{5}{8}$	$2\frac{1}{4}$	$1\frac{1}{4}$ waste	2	$2\frac{1}{2}$ waste	$2\frac{1}{2}$
$\frac{3}{4}$	$2\frac{1}{2}$	$1\frac{1}{2}$ water	$3\frac{1}{4}$	3 waste	$2\frac{1}{2}$
1	$2\frac{3}{4}$	$1\frac{1}{2}$ waste	$2\frac{1}{4}$	4 waste	3

HEATING AND VENTILATION.

STEAM HEATING.

A steam-heating system, with steam having a pressure less than 10 lb. by the gauge, is called a *low-pressure* system. If the steam is at a higher pressure, the system is called *high-pressure* system. When the water of condensation flows back to the boiler by gravity alone, the apparatus is known as a *gravity-circulating* system. When the boiler is run at a high, and the heating system at a low, pressure, the condensed steam must be returned to the boiler by a pump, steam return trap, or injector.

The low-pressure gravity circulating systems considered to be the best are: the *two-pipe system with wet returns; the two-pipe system with dry returns; the one-pipe system, in which all mains, branches, and risers are relieved into a return main below the water-line; and the one-pipe circuit system, in which all pipes are run above the water-line.* The choice of any system will depend upon special conditions and requirements.

RADIATION.

To find the amount of direct radiating surface required to heat a room, basing calculations upon its cubic contents, allow 1 sq. ft. direct radiating surface to the number of cubic feet shown in the following table:

PROPORTION OF RADIATING SURFACE TO VOLUME OF ROOM.

Description.	Cu. Ft.
Bathrooms or living rooms, with 2 or 3 exposures and large amount of glass surface	40
Living rooms, 1 or 2 exposures with large amount of glass surface	50
Sleeping rooms	55– 70
Halls	50– 70
Schoolrooms	60– 80
Large churches and auditoriums	65–100
Lofts, workshops, and factories	75–150

The above ratios will give reasonably good results on ordinary work, if the engineer uses proper judgment in allowing for exposures, leakages through building, etc.

Proportion of Radiating Surface to Glass Surface: *Baldwin's Rule.—*Divide the difference in temperature between that at which the room is to be kept and the coldest outside atmosphere, by the difference between the temperature of the steam pipes and that at which the room is to be kept. The quotient will be the square feet or fraction thereof of plate or pipe surface to each square foot of glass, or its equivalent in wall surface.*

Let S = amount of radiating surface required to counteract the cooling effect of the glass and its equivalent in *exposed* wall surface in square feet;

t = difference in degrees F. between the desired temperature of the room and that of the external air;

t_1 = difference in degrees F. between the temperature of heating surface and that of the air in the room;

s = number of square feet of glass and its equivalent in exposed wall surface.

Then, applying rule, $S = \frac{t}{t_1} s$.

The heating surface found by this rule only compensates for the heat lost by transmission through windows, walls, and

* This rule also applies to hot-water heating.

other cooling surfaces; it does not provide for cold air entering the room through loosely fitting doors, windows, etc., for which an ample allowance must be made. Some buildings are so poorly constructed that 50 per cent. or more must be added to the amount of heating surface obtained by the rule in order to counteract the cooling effect of these air leakages. A common practice is to add 25 per cent. for buildings of ordinary good construction. Ample allowance should be made for rooms exposed to cold winds. It is usual to estimate about 10 sq. ft. of wall surface as equivalent in cooling power to 1 sq. ft. of glass.

PIPING.

SIZES OF STEAM PIPES.

Radiating Surface. Sq. Ft.	1-Pipe Work. In.	2-Pipe Work.		Radiating Surface. Sq. Ft.	1-Pipe Work. In.	2-Pipe Work.	
		Steam In.	Ret. In.			Steam In.	Ret. In.
40– 50	1	¾	¾	1,600– 2,000	4½	4	3½
100– 125	1¼	1	¾	2,000– 2,500	5	4½	4
125– 250	1½	1¼	1	2,500– 3,600	6	5	4½
250– 400	2	1½	1¼	3,600– 5,000	7	6	5
400– 600	2½	2	1½	5,000– 6,500	8	7	6
600– 900	3	2½	2	6,500– 8,000	9	8	6
900–1,200	3½	3	2½	8,000–10,000	10	9	6
1,200–1,600	4	3½	3				

If the mains are high above the boiler, and have short, straight runs, small pipes may be used. If they are unusually low or extremely long or crooked, they should be large. The above table will give good results in ordinary systems.

To determine approximately the size of steam mains or principal risers, *allow 1 sq. in. of sectional area of pipe for each 100 sq. ft. of radiating surface.*

To determine the amount of radiating surface a pipe will supply, *allow 100 sq. ft. for each square inch of sectional area of pipe.*

SIZES OF TAPPINGS FOR PRIME SURFACE RADIATORS.

Direct Radiators.					Indirect Radiators.		
1-Pipe Work.		2-Pipe Work.					
Surface. Sq. Ft.	Size. In.	Surface. Sq. Ft.	Steam. In.	Return. In.	Surf. Sq. Ft.	Steam. In.	Ret. In.
25	1	30	¾	¾	30	1	¾
25– 50	1¼	30– 50	1	¾	30– 50	1¼	1
50– 90	1½	50–100	1¼	1	50–100	1½	1¼
100–160	2	100–160	1½	1¼	100–160	2	1½

DIRECT RADIATORS.

Heat units emitted per hour, per square foot of external surface, per degree of difference in temperature.

VERTICAL TUBES, PRIME SURFACE RADIATORS.

Difference in Temperature. F°.	Tubes Massed.		Single Row Tubes.	
	Height, 40 Inches. B. T. U.	Height, 24 Inches. B. T. U.	Height, 40 Inches. B. T. U.	Height, 24 Inches. B. T. U.
50	1.29	1.54	1.46	2.01
60	1.33	1.58	1.50	2.06
70	1.36	1.62	1.54	2.12
80	1.39	1.66	1.58	2.17
90	1.41	1.70	1.62	2.22
100	1.46	1.74	1.65	2.27
110	1.49	1.78	1.69	2.32
120	1.52	1.82	1.73	2.38
130	1.56	1.86	1.77	2.43
140	1.59	1.90	1.81	2.48
150	1.63	1.94	1.85	2.53
160	1.66	1.98	1.88	2.59
170	1.69	2.02	1.92	2.64
180	1.73	2.06	1.96	2.70
190	1.76	2.10	2.00	2.75
200	1.80	2.14	2.03	2.80
210	1.83	2.18	2.07	2.85
220	1.86	2.22	2.11	2.90
230	1.90	2.27	2.15	2.96
240	1.93	2.31	2.19	3.01

FLUE RADIATORS—NATURAL DRAFT.

Radiating Surface.		B. T. U. Emitted.		Total B. T. U. Emitted.	
Extended. Sq. Ft.	Plain. Sq. Ft.	Extended. Sq. Ft.	Plain. Sq. Ft.	Extended.	Plain.
57.80	40.40	1.65	1.97	95.37	79.58
6.40	4.24	2.05	2.39	13.12	10.13
63.10	41.20	1.39	1.85	87.81	76.22
7.18	4.50	1.90	2.24	13.64	10.08

INDIRECT RADIATORS.

Heat units emitted per square foot of actual surface per hour, per degree of difference in temperature.

NATURAL DRAFT, EXTENDED SURFACES.

Height of Flue. Feet.	Velocity of Air per Second. Feet.	*B. T. U. Emitted.	Height of Flue. Feet.	Velocity of Air per Second. Feet.	B. T. U. Emitted.
5	2.90	1.70	30	6.70	2.60
10	4.10	2.00	35	7.14	2.67
15	5.00	2.22	40	7.50	2.72
20	5.70	2.38	45	7.90	2.76
25	6.30	2.52	50	8.20	2.80

FORCED DRAFT, PLAIN SURFACES.

Velocity of Air per Second. Feet.	*B. T. U. Emitted.	Velocity of Air per Second. Feet.	B. T. U. Emitted.	Velocity of Air per Second. Feet.	B. T. U. Emitted.
3	3.42	8	5.71	18	8.50
4	4.00	10	6.33	20	9.00
5	4.50	12	6.93	22	9.42
6	4.94	14	7.50	24	9.79
7	5.33	16	8.06		

* A *British thermal unit* is the quantity of heat necessary to raise the temperature of 1 lb. of water 1° F.

SIZE OF CHIMNEYS.

Chimneys are proportioned either to the amount of radiating surface in a building, or to the horsepower required for machinery, or to both combined. The draft pressure increases with the height of the chimney. Boilers operating under forced draft from fans or blowers do not require high chimneys, except for the purpose of conveying the gases of combustion above the breathing zone. But in all ordinary buildings the chimneys should be built sufficiently high and large so that forced draft is not necessary.

SIZE OF CHIMNEY FOR GIVEN AMOUNT OF RADIATION, OR HORSEPOWER.

Steam Radiation Sq. Ft.	Horse-power.	Diameter, or Side, of Chimney in Inches.				
		20 ft. High.	40 ft. High.	60 ft. High.	80 ft. High.	100 ft. High.
250	2.5	7.5	6.8	6.3	6.0	6.0
500	5.0	9.5	8.8	8.0	6.5	7.4
750	7.5	11.4	10.3	9.4	8.8	8.5
1,000	10.0	12.8	11.5	10.5	10.0	9.5
1,500	15.0	15.3	13.5	12.5	11.5	11.3
2,000	20.0	17.3	15.3	14.0	13.3	12.5
3,000	30.0	20.5	18.3	16.5	15.8	15.0
4,000	40.0	23.5	20.8	19.0	17.8	17.0
5,000	50.0	26.0	23.0	21.0	19.5	18.5
6,000	60.0	28.5	25.0	22.8	21.3	20.3
7,000	70.0	30.5	27.0	24.5	23.0	21.5
8,000	80.0	32.5	28.5	26.0	24.3	23.5

SIZE OF BOILERS.

No hard-and-fast rules can be employed for determining the heating capacity of boilers or for ascertaining the sizes best adapted for different jobs. The following table is deduced from practical tests and observations by Prof. Carpenter, of Cornell University, and is considered to be within the limits of safety. Two cases are taken: (*A*) when the rate of coal consumption is 10 lb., and (*B*) when it is 8 lb. per sq. ft. of grate surface per hour. The latter is preferable for hot-water heating.

PROPORTIONING PARTS OF HEATING BOILERS.—*Steam Heaters.*

Radiation by Feet.	250	500	750	1,000	1,500	2,000	3,000	4,000	5,000	7,500	10,000
Nominal horsepower	2.5	5	7.5	10	15	20	30	40	50	75	100
Radiating to heating surface	4.5	5.1	5.4	5.6	6	6.2	6.7	6.9	7 | 9*	7 | 9*	7 | 9*
Evaporation per lb. of coal	5.5	5.7	6	6.5	7	7.5	8	8.5	9	9.5	10
Lb. Steam per sq. ft. grate *A*	55	57	60	65	70	75	80	85	90	95	100
Lb. Steam per sq. ft. grate *B*	44	46	48	52	56	60	64	68	72	76	80
Radiating to grate surface *A*	165	171	180	195	210	225	240	255	270	285	300
Radiating to grate surface *B*	132	138	144	156	168	180	192	204	216	228	240
Heating to grate surface *A*	36.5	33.2	33.2	34.8	35	36.2	36.5	37.0	38.5	40.5 | 31.5*	42.5 | 33.3
Heating to grate surface *B*	28.5	27	27.7	27.7	28	29	28.5	29.6	30.8	32.7 | 25.6*	34.5 | 26.5*
Boiler heating surface, sq.ft.	55	98	138	178	250	322	447	580	710	1071 | 833*	1430 | 1111*
Grate surface, sq. ft. ....*A*	1.52	2.92	4.15	5.68	7.15	8.9	12.4	15.7	18.5	26.5	33.3
Grate surface, sq. ft. ....*B*	1.88	3.88	5.4	6.37	8.92	11.2	15.5	19.5	23.2	32.5	41.5
Diam. safety valve, in.........	1.5	2.25	2.5	2.75	3	3.25	3.5	4	4	two 3-inch	two 4-inch
Diam. smoke pipe, in.	7	10	11	12	15	17	19	23	25	28	34

Hot-Water Heaters.

Radiation by Feet.	250	500	750	1,000	1,500	2,000	3,000	4,000	5,000	7,500	10,000
Radiating to heating surface	6.8	7.6	8.1	8.4	9	9.3	10	10.4	10.5	10.5 | 13.5*	10.5 | 13.5*
Radiating to grate surface *A*	247	256	270	292	315	337	360	382	405	427	450
Radiating to grate surface *B*	193	207	216	232	252	270	288	306	324	342	360
Heating to grate surface *A*	36.5	33.2	33.2	34.8	35	36.2	36.5	37	38.5	40.5 | 31.5	42.5 | 33.3
Heating to grate surface *B*	28.5	27	26.7	27.7	28	29	28.5	29.6	30.8	32.7 | 25.6*	34.5 | 26.5*
Heating surface, sq. ft.	36.5	65	91.5	118	166	215	296	385	470	703	905
Grate surface, sq. ft. ....*A*	1	1.96	2.75	3.75	4.75	5.9	8.2	10.4	13.3	17.6	22.2
Grate surface, sq. ft. ....*B*	1.25	2.58	3.6	4.25	5.9	7.1	10.3	13	15.3	21.5	27.5
Diam. smoke flue, in.	7	10	11	12	15	17	19	23	25	28	34

* Water-tube boiler.

EXHAUST-STEAM HEATING.

Exhaust steam turned into a heating system creates a back pressure on the engine, which must be avoided as much as possible by using large steam-distributing pipes. A direct connection to the boilers through a pressure-reducing valve must be employed, to automatically furnish steam when the exhaust fails; and a relief valve should be placed upon the system so that surplus exhaust steam may escape. Before the steam enters the system, the 20 or 25 per cent. of water and oil it usually contains should be removed.

To proportion an exhaust-heating system, it is necessary to know the weight of steam discharged from the engine, in order to determine how many square feet of radiating surface are required to properly condense the steam.

WEIGHT OF WATER USED PER HOUR PER INDICATED HORSEPOWER.

Class of Non-Condensing Engine.	Weight of Water. Pounds.
Compound automatic	25
Simple Corliss	30
Simple automatic	35
Simple throttling	40

From these figures about 10 per cent. must be deducted for cylinder condensation, etc., in order to obtain the real available weight of steam for heating purposes.

RATIO BETWEEN CUBIC CONTENTS AND RADIATOR SURFACE FOR EXHAUST HEATING.

Class of Building.	Direct Radiation.	Indirect Radiation.	Blower System.
	S. Ft. C. Ft.	S. Ft. C. Ft.	S. Ft. C. Ft.
Dwellings	1 to 50	1 to 40	1 to 300
Offices	1 to 70	1 to 60	1 to 365
Stores and shops	1 to 100	1 to 80	1 to 500
Churches, etc.	1 to 200	1 to 150	1 to 900

The figures on page 307 are reasonable averages, and allowances must be made for exposure, etc.

Each square foot of direct radiating surface gives off to the air around it about $1\frac{1}{2}$ Thermal Units per hour per degree of difference between the temperature of the steam and that of the surrounding air. This is equivalent to about $\frac{1}{4}$ lb. of steam per hour; or, from 4 to $4\frac{1}{4}$ sq. ft. of surface to each pound of steam to be condensed.

HOT-WATER HEATING.

The circulation in a hot-water heating system is a movement of hot water from the boiler to the radiators, where it parts with some heat, and a consequent movement of colder water from the radiators to the boiler to become reheated. Without circulation heat cannot be conveyed from the boiler to the radiators. The velocity of circulation depends chiefly upon: (*a*) the difference between the mean density of the ascending current and that of the returning current; (*b*) the vertical height of circuit above the boiler; and (*c*) the resistance to flow due to friction, change in direction, etc. The theoretical velocity could easily be computed, but, as it is only imaginary, is of little value to the practical man; and, further, the actual velocity bears no definite ratio to the theoretical.

RADIATING SURFACE.

The sizes of pipes should be governed by the amount of radiating surface to be supplied, the height of the radiators above the boiler, and the number of changes in the direction of the several currents. It is considered safe practice to *allow from 50 to 100 square feet of direct radiation for each square inch of cross-section in the pipe.* If the pipes are short, straight, and high, 1 to 100 would be allowed; if long, crooked, or low, 1 to 50 or more, according to the conditions.

To determine the amount of radiating surface necessary to easily warm a building in all kinds of weather, and to proportion it so that each room will have the required temperature at the same time, are very important points, requiring

careful consideration. No rules can be given applicable to all cases, but for ordinary buildings having the average wall and glass exposures, the following table is found in practice to give good results, when used with judgment.

RATIO OF HOT-WATER RADIATING SURFACE TO VOLUME OF ROOM.

Direct Radiation. Average Temperature in Radiators, 160° F.

Name of Room.	Ratio, 1 Sq. Ft. to Cu. Ft.
Living rooms, one side exposed	30
Living rooms, two sides exposed	28
Living rooms, three sides exposed	25
Sleeping rooms	30– 40
Hall and bathrooms	20– 30
Schoolrooms and offices	30– 50
Factories and stores	50– 70
Auditoriums and churches	80–100

For direct-indirect radiation allow at least 25 per cent. extra. For indirect radiation allow 50 per cent. extra.

Due allowance must be made for leakages through loose doors, windows, etc.

PIPING.

SIZES OF TAPPINGS FOR HOT-WATER RADIATORS.

Direct Radiators.				Indirect Radiators.	
First Floor.		Second Floor.			
Surface. Sq. Ft.	Size. In.	Surface. Sq. Ft.	Size. In.	Surface. Sq. Ft.	Size. In.
0–15	$\frac{3}{4}$	0–20	$\frac{3}{4}$	0–40	1
15–50	1	20–70	1	40–90	$1\frac{1}{4}$
50–100	$1\frac{1}{4}$	70–125	$1\frac{1}{4}$	90–150	$1\frac{1}{2}$
100–	$1\frac{1}{2}$	125–	$1\frac{1}{2}$	150–	2

Radiating Surface Supplied by Hot-Water Mains.

Direct Radiation. Fall of Temperature, 20°. Height of Circuit, from 10 to 15 feet.

Diameter of Mains. Inches.	Total Estimated Length of Circuit in Lineal Feet.									
	100 Sq. Ft.	200 Sq. Ft.	300 Sq. Ft.	400 Sq. Ft.	500 Sq. Ft.	600 Sq. Ft.	700 Sq. Ft.	800 Sq. Ft.	900 Sq. Ft.	1,000 Sq. Ft.
1	20									
1¼	35	20								
1½	56	40	25							
2	116	85	70	50						
2½	220	150	120	100	90					
3	345	240	200	170	150	140	125	110	100	90
3½	500	340	280	245	225	205	190	175	162	150
4	700	485	390	340	310	280	260	240	230	220
4½	925	640	535	460	410	375	345	325	300	295
5	1,200	830	700	600	540	490	450	420	400	380
6	1,900	1,325	1,100	950	850	775	700	650	620	600
7		2,000	1,600	1,400	1,250	1,140	1,050	975	925	875
8				1,970	1,720	1,550	1,440	1,350	1,300	1,250
9							1,900	1,800	1,700	1,620

Diameter of Radiator Connections.

Direct Radiation. Fall of Temperature, 20°.

Size of pipe in inches	¾	1	1¼	1½	2	2½
Area in square feet	16	24	40	60	120	240

The sectional area of the mains should approximate the sum of the area of its branches, but in many cases, particularly where there is no indirect work, the sizes may be a little less.

The fittings used on hot-water mains should all have easy curves and the branches should be Y's, to reduce resistance to a minimum. Special distributing fittings should be used to induce circulation through radiators on the first floor.

Sizes of Mains and Branches.

Sizes of Main. *Sizes of Branches.*

1″ will supply two ¾″.
1¼″ will supply two 1″; or one 1″ and two ¾″.
1½″ will supply two 1¼″; or one 1¼″ and two 1″.
2″ will supply two 1½″; or one 1½″ and two 1¼″.
2½″ will supply two 1½″ and one 1¼″; or one 2″ and one 1¼″.
3″ will supply one 2½″ and one 2″; or two 2″ and one 1½″.
3½″ will supply two 2½″ ; or one 3″ and one 2″; or three 2″.
4″ will supply one 3½″ and one 2½″; or two 3″; or four 2″.
4½″ will supply one 3½″ and one 3″; or one 4″ and one 2½″.
5″ will supply one 4″ and one 3″; or one 4½″ and one 2½″.
6″ will supply two 4″ and one 3″; or four 3″; or ten 2″.
7″ will supply one 6″ and one 4″; or three 4″ and one 2″.
8″ will supply two 6″ and one 5″; or five 4″ and two 2″.

All flow and return pipes should be of the same size.

All pipes must rise from the boiler to the radiators with a pitch of at least 1 in. in 10 ft.

The expansion-tank capacity should be at least $\frac{1}{20}$ that of the entire apparatus, if it is an open tank. Closed tanks are not to be recommended.

Radiating Surface Supplied by Hot-Water Risers.

Direct Radiation. Fall of Temperature, 20°.

Diameter of Riser. Inches.	Story Where Heater is Located.					
	1 Sq. Ft.	2 Sq. Ft.	3 Sq. Ft.	4 Sq. Ft.	5 Sq. Ft.	6 Sq. Ft.
¾	12	17	21	24		
1	22	32	40	48		
1¼	38	56	70	80	88	
1½	66	92	112	132	145	
2	140	196	238	280	310	
2½	240	328	400	470	515	
3	350	490	595	700	770	850
3½	510	705	860	1,010	1,110	1,215
4	700	980	1,190	1,280	1,540	1,660

There is a practical limit to the advantageous vertical length of risers, especially with the smaller pipes. If a small riser extends to a great height, the friction becomes excessive, and the quantity of water delivered will be much smaller than it would otherwise be.

LIMITING HEIGHT OF RISERS.

Diameter in inches	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2
Height in feet	20	30	45	60	80

The horizontal pipes on the upper floors of a building, and also the risers leading thereto, may be made smaller in diameter than those upon the lower floors, because the force which impels the water increases with the height of the circuits. The proper size of a pipe having been determined for a given service on the first floor, the diameter for equal service on higher floors—the temperatures remaining the same—may be found by multiplying by the following factors:

Story	2d	3d	4th	5th
Factor	.87	.80	.76	.73

The area of heating surface that may be properly supplied by a pipe of given diameter will increase as the circuit is made higher. If the area which is known to be right for a given size of pipe on the first floor, be taken as 1, the areas on the upper floors will increase in the following order:

Story	2d	3d	4th	5th
Proper area heating surface	1.40	1.70	1.98	2.20

FURNACE HEATING.

It is assumed in the following rules and tables that the average temperature of the hot air in the flues is about 120°, and that the air is moved solely by natural draft.

A simple method for proportioning hot-air pipes to deliver a given volume of air to the several floors is to assume that 1 sq. in. of stack, or flue, area will supply 100 cu. ft. of air per hour at the first floor, 125 at the second floor, and 150 at the third floor.

RATIO OF AREA OF HOT-AIR PIPES TO VOLUME OF ROOM.

Rooms.	Ratio. 1 Sq. In. to Cu. Ft.
First-floor rooms, moderate exposure	30
First-floor rooms, great exposure	20–25
Second-floor rooms	25–35
Third-floor rooms	30–40

A more accurate method is as follows:

Rule.—*For rooms on the first floor, add together the total glass surface and ¼ the area of the exposed walls in square feet, and multiply the total by 1.5; the product is the proper area of the pipe in square inches. For second-story rooms, multiply by 1 to 1.25, according to the exposure; and for the third story, by .75 to 1.*

If leaders are of considerable length, their area should be about ¼ greater than the connecting stacks.

SIZE OF HOT-AIR PIPES AND REGISTERS.

First-Floor Rooms.				Second-Floor Rooms.			
Size of Register. In.	Diameter of Pipe. In.	Size of Rooms. Ft.	Height of Ceiling. Ft.	Size of Register. In.	Diameter of Pipe. In.	Size of Rooms. Ft.	Height of Ceiling. Ft.
12 × 15	12	16 × 16 to 18 × 20	11	10 × 14	10	16 × 16 to 18 × 20	10
10 × 12 or 10 × 14	10	14 × 14 to 15 × 15	10	9 × 12	9	14 × 14 to 16 × 16	9
9 × 12	9	12 × 12 to 14 × 15	9	8 × 12	8	10 × 10 to 13 × 14	8
8 × 12	8	8 × 12 to 13 × 13	9	8 × 10	7	7 × 12 to 12 × 12	8

AREA OF RECTANGULAR REGISTERS.

Size of Opening. In.	Net Area. Sq. In.	Size of Opening. In.	Net Area Sq. In.
6 × 10	40	14 × 22	205
8 × 10	53	15 × 25	250
8 × 12	64	16 × 24	256
8 × 15	80	20 × 20	267
9 × 12	72	20 × 24	320
9 × 14	84	20 × 26	347
10 × 12	80	21 × 29	400
10 × 14	93	27 × 27	486
10 × 16	107	27 × 38	684
12 × 15	120	30 × 30	600
12 × 19	152		

AREA OF ROUND REGISTERS.

Diam. of Opening. In.	Net Area. Sq. In.	Diam. of Opening. In.	Net Area. Sq. In.
7	26	16	134
8	33	18	169
9	42	20	209
10	52	24	301
12	75	30	471
14	103	36	679

VENTILATION.

Ventilation is a process of moving foul air from any space and replacing it with fresh air. A positive displacement, however, does not take place; the incoming fresh air chiefly dilutes the foul air to a point suitable for healthful respiration.

Pure air, such as exists in the open country, contains about 4 parts of carbonic acid (CO_2) per 10,000 parts of air, while badly ventilated rooms often contain as much as 80

parts of CO_2 per 10,000 of air. Hygienists, after careful study, have decided that an increase of 2 parts of CO_2 per 10,000 of air should be accepted as the *standard of respirable purity*, and any excess of CO_2 above this may be considered as vitiation.

PRODUCTION OF CO_2 PER HOUR.

Source.	Cu. Ft.
Adult man	.6
One cubic foot of gas, burning	.8
Ordinary lamp	1.0
Candle	.3

Taking the figures above given—4 parts of CO_2 per 10,000 parts of fresh air, and 6 parts ($= 4 + 2$) per 10,000 of vitiated air—as the standard for proper health conditions, it is found that 3,000 cu. ft. of fresh air per hour are necessary for each adult person. If a different standard than 6 is used, the number of cubic feet per person will be found by dividing 6,000 by the difference between this standard and 4.

If any lights deliver their products of combustion into the room, the amount of CO_2 given off by them should be converted into its equivalent in men, thus: One ordinary gas light equals in vitiating effect about $5\frac{1}{2}$ men, an ordinary lamp $1\frac{2}{3}$ men, and an ordinary candle about $\frac{1}{2}$ man.

It is considered good practice to allow 2,000 cu. ft. of fresh air per hour for each inmate of a room or auditorium. Hospitals and such places, where the vitiation is due to exhalations from diseased or sick people, should be provided with at least twice this amount.

NATURAL VENTILATION.

In natural ventilation systems, the drafts in the flues or ducts are caused by the difference in density between the air in the ducts and the outer atmosphere. The higher the temperature in the ducts, the more rapid will the draft become.

In the following table 50 per cent. (a fair average in good work) has been deducted from the theoretical flow, to offset

all ordinary resistances in the flues, such as friction, change in direction, etc. The difference in temperature given in the table is that existing between the outer atmosphere and the average of the air in the flue. Knowing the velocity per minute, and the cubic feet of air per minute to be removed, the area of the flue in square feet is found by dividing the volume by the velocity.

FLOW OF AIR IN FLUES PER SQUARE FOOT OF SECTION.
By Natural Draft, in Cubic Feet per Minute.

Difference in Temp. F°.	Height of Flue in Feet.								
	10 Cu. Ft.	15 Cu. Ft.	20 Cu. Ft.	30 Cu. Ft.	40 Cu. Ft.	50 Cu. Ft.	60 Cu. Ft.	80 Cu. Ft.	100 Cu. Ft.
10	108	133	153	188	217	242	264	306	342
15	133	162	188	230	265	297	325	375	420
20	153	188	217	265	306	342	373	435	485
25	171	210	242	297	342	383	420	485	530
30	188	230	265	325	375	419	461	530	594
40	216	265	305	374	431	482	529	608	680
50	242	297	342	419	484	541	594	680	768
60	266	327	376	460	532	595	650	747	842
70	288	354	407	498	576	644	703	809	910
80	308	379	435	533	616	688	751	866	972
90	326	401	460	565	652	728	795	918	1,029
100	342	419	484	593	684	765	835	965	1,080
125	384	470	541	664	766	857	939	1,085	1,216
150	419	514	593	726	838	937	1,028	1,185	1,325

FORCED VENTILATION.

There are two classes of forced ventilation : (1) The *plenum* system, in which the air pressure in the building is slightly greater than that of the outer atmosphere ; in other words, that system by which air is blown through the building by a fan or other blower placed at the inlet. (2) The *vacuum* system, or that method of removing foul air, and causing a consequent inrush of fresh air, by an exhaust fan placed at the outlet to the vent flue or stack. In the latter system, the

air pressure in the building is slightly lower than that of the outer atmosphere. The plenum system is the more wholesome and preferable method.

The capacity of a fan, that is, the amount of air which it will deliver, depends considerably upon the construction of the fan, and upon the resistance to the flow of the air.

The following table shows a safe capacity for some leading forms of blowers and exhaust fans, operating against a pressure of 1 oz. per sq. in., or $1\frac{3}{4}$ in. water, nearly:

Diameter of Wheel. Ft.	Revolutions per Minute.	Horsepower Required.	Capacity per Minute. Cu. Ft.
4	350	6.0	10,600
5	325	9.4	17,000
6	275	13.5	29,600
7	230	18.4	42,700
8	200	24.0	46,000
9	175	29.0	56,800
10	160	35.5	70,300

If the resistance is greater than above given, the required capacity may be obtained by increasing the number of revolutions, increasing the horsepower correspondingly. Or, if the resistance is less, the required capacity may be obtained by reducing the number of revolutions, with a corresponding decrease of power.

In selecting a fan, it is advisable to choose a large one, so that it may run easily, quietly, and economically. A small fan, which must be run at high speed, wastes too much energy, and often makes a disagreeable noise.

Fresh-air inlets, if near the floor, should be so arranged that the velocity of inlet will not exceed 2 ft. per second; a higher velocity is considered a perceptible draft. Higher velocities, however, are permissible if the inlets are located more than 8 ft. above the floor. Vent-flue inlets can safely be made to operate with a velocity of 6 or 8 ft. per second, without the air-current being disagreeably perceptible.

GAS AND GAS-FITTING.

GAS.

KINDS OF GAS.

Coal gas is made by heating bituminous coal in air-tight boxes or retorts. The heat breaks up the combinations of hydrogen and carbon in the coal, transforming them into other compounds, most of which are gaseous at ordinary temperatures. Among the new compounds thus made are tar, ammonia, and sulphureted hydrogen. The tar and ammonia are condensed and removed. The gas also undergoes purification and scrubbing; in the former process, the gas is forced in thin streams through pans filled with lime, oxide of iron, etc.; and in the latter, through bodies of liquid charged with certain chemicals.

Oil gas is made from petroleum in a similar way and from almost any kind of oil, grease, or fat.

Producer gas differs from the coal gas commonly used for lighting, in having much less combustible matter, and in having a large percentage of nitrogen. It is made by burning anthracite or bituminous coal in a closed furnace, with a supply of air too small for complete combustion. The average quality of producer gas contains from 10 to 15 per cent. of hydrogen, from 20 to 30 per cent. of carbon monoxide (CO), and from 40 to 60 per cent. of nitrogen. Producer gas burns with a dull reddish flame, and its heating value is about one-fourth that of good coal gas.

Water gas is made from anthracite coal and steam. The coal is placed in an air-tight cylinder, ignited, and raised to an incandescent heat by an air blast; the blast is then shut off, and dry steam is blown through the glowing fuel. The intense heat breaks up the steam into free oxygen and hydrogen. the oxygen combining with the hot carbon, forming CO, and the hydrogen passing along with it, but not combining. These are then led to a gas holder. The operations of blowing up and making gas alternate at intervals of about

3 minutes, until the fuel is exhausted. The fresh gas burns perfectly in heating burners, but when used for lighting purposes, is always enriched in carbon, by the vaporization of petroleum before it leaves the generator. The density of pure water gas is .4 that of air. It naturally has very little odor, but some impurities are allowed to remain to give the gas a perceptible odor.

Acetylene (chemical symbol, C_2H_2) is composed of 12 parts of carbon to 1 of hydrogen by weight, or 92.3 per cent. carbon and 7.7 per cent. hydrogen. It is the most brilliant illuminating gas known. Its density is about .91, and its weight at 32° F. is .073 lb. per cu. ft. It is without color, and has a strong odor, like garlic. It is poisonous to breathe, in about the same degree as ordinary gas. The heat developed by the combustion of 1 cu. ft. is theoretically 1,090 heat units. Acetylene is manufactured by mixing calcium carbide with water. The carbide is a mixture of coke and lime which had been fused in an electric furnace. It is reddish brown, or gray, in color, somewhat crystalline, and decomposes water like ordinary quicklime; the calcium takes oxygen from the water, forming oxide of calcium, or common quicklime, while the carbon combines with the hydrogen of the water, and forms the desired compound, acetylene. Considerable heat is given off during the operation.

Pure carbide of calcium will yield 5.4 cu. ft. of acetylene per pound; but it is hardly safe to reckon upon more than 4.5 cu. ft. from the commercial carbide. Special burners are required for acetylene illumination, provided with small air holes to supply more air to the flame than is obtained by ordinary burners. Acetylene will give a light of about 240 candlepower when burned at the rate of 5 cu. ft. per hour, while good coal gas only gives 16 candlepower at the same rate of combustion. Acetylene can be reduced to liquid form, at a temperature of 60°, by a pressure of about 600 lb. per sq. in., but is then unsuitable for use in buildings, owing to the danger of explosion. Acetylene corrodes silver and copper, forming explosive compounds, but does not affect brass, iron, lead, tin, or zinc. These facts should be borne in mind when constructing apparatus for its use.

Gasoline gas, or *carbureted air*, sometimes called *air gas*, is a mixture of gasoline vapor with air, and, when pure, is so rich in carbon that special burners must be employed for lighting purposes. The quantity required to produce 1,000 cu. ft. of gas of from 14 to 16 candlepower is about 4½ gal. of the best grade, and more if the gasoline is of a lower grade. The specific gravity of gasoline is about .74 that of water. The temperature of a gasoline-gas machine should range between 40° to 80°. The highest grade of gasoline, that is, the grade that will evaporate most freely at ordinary temperatures, should be used for winter service. The generators should be located outside the building, in a sheltered place. An air pump is used to pump fresh air through the generator, and a mixing device is commonly employed for mixing air with the gas before it reaches the burners. The pump and mixer are usually located in the cellar of the building.

PRESSURE OF GAS.

If a gas is lighter than air, at the same temperature, the pressure will be greatest at the top of the chamber containing the gas; if heavier, the greatest pressure will be at the bottom of the chamber. The upward pressure of gas having a less density than air is caused by its deficiency in weight, and consequent inability to balance the pressure of the atmosphere.

For illustration, consider a column of gas 1 ft. square and 100 ft. high, having a density of .5, or one-half that of air, the temperature being the same as that of the atmosphere—say 60°. Air at 60° weighs .0764 lb. per cu. ft., and as the column contains 100 cu. ft., it will weigh $.0764 \times 100 = 7.64$ lb. The gas having a density of .5 will weigh only half as much, or 3.82 lb., and is, therefore, unable to balance an equal volume of air. Consequently, it is pressed upwards with a force of $7.64 - 3.82 = 3.82$ lb. against the top of the chamber which contains it. Whatever the actual pressure of the gas may be at the bottom of the column, it will, in this case, be increased at the top to the extent of 3.82 lb. per sq. ft.

The increase of pressure in each 10 ft. of rise in the pipes, with gas of various densities, is shown in the following table:

Rise in pressure (in. of water)	0.	.0147	.0293	.044	.058	.073	.088	.102
Density of gas	1.	.9	.8	.7	.6	.5	.4	.3

EXAMPLE.—The pressure in the basement, at the meter, is 1.2 in. of water; what will be the pressure on the sixth story, 70 ft. above, the density of the gas being .4?

SOLUTION.—The table shows that the increase will be .088 for each 10 ft. of rise; therefore, .088 × 7 = .616 increase. Then pressure at sixth story = 1.2 + .616 = 1.816 in.

MEASUREMENT OF PRESSURE AND FLOW.

Pressure.—The pressure of gas is measured by the common water gauge, which is shown in Fig. 16. The tubes *b* and *c* are glass, and are filled with water up to the zero of the scale, which is graduated in inches and fifths or tenths of an inch. The tube *c* is opened to the air at the top. When pressure is admitted to *a*, the water will sink in the tube *b*, and will rise in *c*. The difference in the height of the water in the two tubes, measured in inches, is the measure of the pressure exerted in *inches of water*. For measuring heavier pressures, mercury is used instead of water.

FIG. 16.

Pressures measured in inches of water or mercury may be translated into pounds per square inch or square foot, by multiplying the reading by the following figures:

1 in. of water at 62° F. = 5.2020 lb. per sq. ft.
1 in. of water at 62° F. = .0362 lb. per sq. in.
1 in. of mercury 62° F. = .4897 lb. per sq. in.

Pressure per square inch or square foot may be converted into inches or feet of water, or inches of mercury, by multiplying the pressures by the following figures:

1 lb. per sq. ft. = .1923 in. of water at 62° F.
1 lb. per sq. in. = 27.70 in. of water at 62° F.
1 lb. per sq. in. = .2042 in. of mercury at 62° F.

Flow.—The volume of gas, passing through a pipe in a given time, is computed by multiplying the velocity by the area of the pipe. The velocity may be measured by a Pitot tube, as shown in Fig. 17. This consists of two tubes, *a* and *b*, inserted in a plug *c*, the lower end of *a* being square, and that of *b* curved to face the current; the upper ends are connected to a water gauge *d*. Gas entering through *b* depresses the water column as shown; the velocity corresponding to the reading is found from tables which are generally furnished with the instrument.

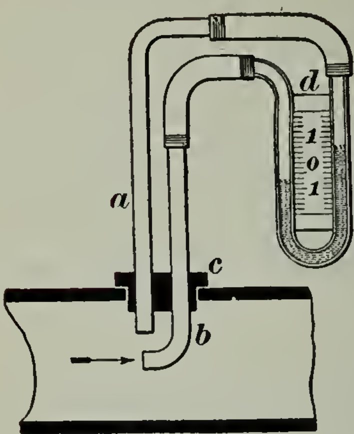


FIG. 17.

The actual quantity of the gas is computed by correcting the volume for temperature and pressure, reducing it to a volume at standard temperature of 32° F. and standard pressure of 1 in. of water. The correction for temperature may be made as follows:

Rule 1.—*Multiply the measured volume by 492 and divide the product by 460 plus the actual temperature. The quotient will be the volume at 32° F.*

The correction for pressure may be made as follows:

Rule 2.—*Multiply the volume at 32° F. by the pressure in inches of water plus 407, and divide the product by 408. The quotient will be the volume at 1 inch pressure, and at 32° F.*

EXAMPLE.—A pipe passes 1,000 cu. ft. of gas per hour, under a pressure of 8 in. of water and at a temperature of 60°. What will the volume be when the pressure is reduced to 1 in., and the temperature to 32°?

SOLUTION.—By the first rule, the volume at 32° is

$$\frac{1{,}000 \times 492}{460 + 60} = 946.1 \text{ cu. ft.}$$

By rule 2, the volume under 1 in. pressure and at 32° is

$$\frac{946.1 \times (8 + 407)}{408} = 962.3 \text{ cu. ft.}$$

If the quantity of gas delivered through a pipe of given

length is known, that supplied through a longer or shorter pipe is to the known volume as the square root of the given length is to the square root of the required length. With pipes of the same length and diameter, the volumes delivered at any proposed pressure is to that supplied at any other pressure as the square root of the proposed pressure is to the square root of the given pressure.

GAS METERS AND PRESSURE REGULATORS.

Meters.—For ordinary purposes, the volume of gas passing through a pipe is measured by an apparatus called a *gas meter*. A gas meter measures the volume only, and its indications are not affected by any change that may occur in the pressure of the gas. The difficulty thus encountered in correctly measuring the volume of gas actually delivered under varying pressures, is overcome by using a governor between the meter and the street main, or service pipe. The governor is a species of reducing valve which will receive gas at any pressure, whether steady or variable, and will discharge it at a steady low pressure.

Fig. 18 shows a meter of the ordinary type. To read

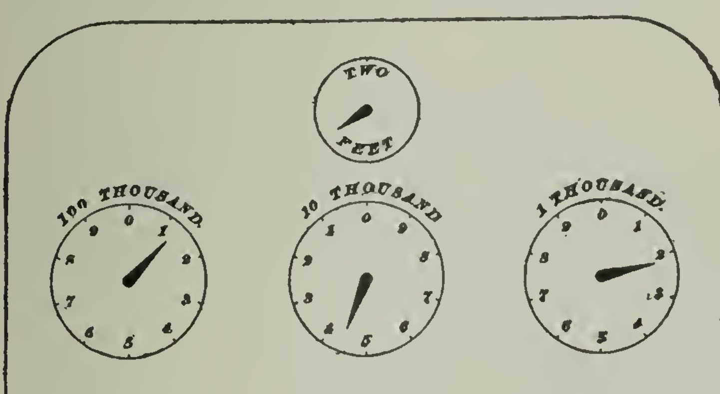


FIG. 18.

such a meter, note the lesser of the two figures between which each hand points, or the figure to which it points, beginning at the left-hand dial; then add two ciphers to the right of the three figures, and the number so obtained will be the

amount of gas in cubic feet which the meter has measured. Thus the pointers in the diagram indicate that 14,200 cu. ft. of gas have passed through the meter.

The dial marked *two feet* may be used to ascertain the quantity of gas consumed per hour by a burner, by noting the time required for the pointer to make a revolution. Thus, the hand will make 2½ revolutions per hour if 5 cu. ft. pass through the meter in that time. This dial may also be used in testing for leaks.

Pressure Regulators.—The objects sought in the use of pressure regulators or governors are economy in the consumption of gas, steadiness of the lights, and most effective operation of the burners. It is of great importance that both volume and pressure at the burners should be closely regulated. The amount of gas wasted by over pressure is much greater than is generally believed. A good new lava-tip burner consuming 5 cu. ft. per hour at .5 in. pressure, will consume about .5 of a cu. ft. more for each increase of .1 in. in the pressure. Thus an over pressure of .1 in. will increase the gas bill about 10 per cent. The variation, in even the best regulated systems, is usually much greater than one-tenth inch, and is frequently ten-tenths or more.

The two systems of regulation in use are the *pressure* and the *volumetric* regulation. In the first system, a governor is attached to the service pipe at the meter, and the house distributing pipes are maintained at constant pressure; in the second system, each burner is supplied with a governor, the pressure in the pipes not being controlled.

The proper place for a pressure regulator, if used, is between the meter and the main. The meter should then be adjusted to suit the house pressure instead of the street pressure.

The pressure required at the burners, to secure the best results, varies greatly in different forms of apparatus. The following are the pressures generally used:

Argand burners	.2 in. of water.
Common batswing burners	.5 in. of water.
Wellsbach incandescent burners	.5 or more.
Wenham and Lebrun lamps	.5 to 1 or more.
Atmospheric burners	1.0 or more.

GAS-FITTING.

ILLUMINATION REQUIRED.

The number of gas lights required to properly illuminate a room depends on its size, condition of wall surfaces, etc. The reflection from the walls in small rooms is proportionately greater than in large ones, and hence a less number of burners is required in proportion to the floor space. A 5′ (cubic feet per hour) batswing burner is assumed to give a light of 16 candlepower under a pressure of .5 in. of water.

For large rooms, such as a church, etc., the proper illumination will be furnished by using *one burner to each 40 sq. ft. of floor.* If there are balconies, etc., extra lights must be provided according to the same rule. For smaller rooms, such as are found in ordinary dwellings, the proportion may be *1 light to about 80 sq. ft. of floor.* The amount of light required is, therefore, from .4 to .2 candlepower per square foot, according to the size of the room.

If incandescent gas lights, such as the Welsbach, are used, the number of lights may be much less, as these lights furnish from 50 to 60 candlepower on a consumption of about 3 cu. ft. of gas per hour, at a pressure of .5 in.

SIZE OF PIPES.

Each pipe must have enough capacity to supply all its burners when they are in full operation. Allowance must also be made for all heating and cooking apparatus likely to be required. The quantity required for lighting may be reckoned as 5 cu. ft. per hour for each burner, unless otherwise given. The actual quantity required by improved burners, however, differs so much that it is impracticable to compute the volume required by merely noting the number of burners.

Service pipes should never be less than ¾ in. because of liability to chokage, and, if of iron, it is advisable to make the diameter at least 1 in. For small cook stoves, the supply pipe should be at least ¾ in., and for larger stoves, 1 to 1½ in.

Having ascertained the probable maximum quantity required in cubic feet per hour, the diameter of the pipe can be found from the following table. If the length of the proposed pipe exceeds the maximum length given, the next larger size pipe should be chosen. If the pressure exceeds 2 in., the principal pipes may be reduced one size. If the pressure is less than 1 in., all pipes must be increased one size, and with very long pipes, the diameter will require to be increased still more. When gasoline gas is used, no distributing pipe should be less than $\frac{3}{8}$ in.

CAPACITY OF GAS PIPES.

Diameter of Pipe. In.	Maximum Length. Ft.	Capacity per Hour.	
		Coal Gas. Cu. Ft.	Gasoline Gas. Cu. Ft.
$\frac{1}{4}$	6	10	
$\frac{3}{8}$	20	15	10
$\frac{1}{2}$	30	30	20
$\frac{3}{4}$	50	100	75
1	70	175	125
$1\frac{1}{4}$	100	300	200
$1\frac{1}{2}$	150	500	350
2	200	1,000	700
$2\frac{1}{2}$	300	1,500	1,100
3	450	2,250	1,500
4	600	3,750	2,500

In this table, the pressure is assumed to be about 2 in. of water. The quantities stated are those which the pipes will deliver at the burners without objectionable fall of pressure.

INSTALLATION AND TESTING.

The pipes used for the distribution of gas in buildings are standard plain wrought-iron or steel pipe.

If the location of the pipes is not shown by the architect, then the gas-fitter must use his own judgment in determining their position. He should be governed by the following considerations:

1. The pipes should run to the fixtures in the most direct manner practicable.

2. The pipes must be graded to secure proper drainage without excessive cutting of floorbeams, or otherwise damaging the building.

3. Pipes which run crossways of floorbeams should be laid not more than 1 ft. from the wall, to avoid serious injury to the floor.

4. Fixtures should be supplied by risers rather than by drop pipes, as far as practicable.

5. All pipes should be located where they can be got at for repairs, with the least possible damage to the floors or walls.

6. The fittings should be malleable iron galvanized, beaded fittings being preferable to plain ones. Plain black iron fittings should never be used on important work.

Testing.—As soon as the pipes are all in place and are properly secured, the system should be tested to find if it is gas-tight. Air should be forced in the system until the gauge indicates 15 or 20 in. of mercury, or 7 to 10 lb. per sq. in., the pressure being continued for about an hour, and if the gauge shows a falling off in pressure of more than $\frac{1}{4}$ in. of mercury, or $\frac{1}{8}$ lb. per sq. in., then the system cannot be passed as perfect. The mercury-column differential proving gauge is well adapted for testing gas pipes, etc., which are to be made air-tight; common spring gauges are unreliable.

The extent of a leak may be judged by the rapidity of the fall in pressure, but its location must be found by the sense of smell. For this purpose a small quantity of ether should be introduced into the pipes. The vapor of the ether will diffuse throughout the system and escape from the leak, where it will be detected by its odor. The gauge should be provided with an ether cup especially for testing purposes.

In case of large buildings, it is advisable to test the piping in sections, say one floor at a time, because it is much easier to locate leaks. After each section is tested they may be connected, and then subjected to a final test.

The pipes should not be covered until the tests are completed. The owner, architect, or inspector should witness the tests.

ESTIMATING.

APPROXIMATE ESTIMATES.

The following table shows the approximate cost per cubic foot of various kinds of structures. In computing the contents of a building there is no uniformity in practice, but no great error will be made in figuring the solid contents from floor of cellar to ridge of roof.

Cost of Buildings per Cubic Foot.

Class of Building.	Cost per Cu. Ft. Cents.
Small frame buildings, costing from $800 to $1,500	8 to 9
Frame houses, 8 to 12 rooms, costing from $1,500 to $10,000	9 to 11
Brick houses, 8 to 10 rooms	10 to 14
Highly finished city dwellings (brick or stone)	17 to 20
Schoolhouses (brick)	9 to 11
Churches (stone)	20 to 25
Office buildings (well finished)	30 to 40
Hospitals, libraries, and hotels	32 to 44

STONEWORK.

Stone masonry is usually measured by the perch; in some sections of the country, however, measurement by the cord is preferred, but the best method (as being invariable) is by the cubic yard. In estimating by the perch, it should be stated how much the perch is taken at, whether 24¾ or 25 cu. ft. Note should also be made in regard to deduction for openings, as in most localities it is not customary to deduct those under a certain size, and corners are usually measured twice.

Rough stone from the quarry is usually sold under two classifications, namely, rubble and dimension stone. *Rubble* consists of pieces of irregular size, such as are most easily obtained from the quarry, up to 12 in. in thickness by 24 in.

in length. Stone ordered of a certain size, or to square over 24 in. each way and to be of a particular thickness, is called *dimension stone.*

Rubble masonry and stone backing are generally figured by the perch or the cubic yard. Dimension-stone footings are measured by the square foot unless they are built of large irregular stone, in which case they are measured the same as rubble. Ashlar work is always figured by the superficial foot; openings are usually deducted and the jambs are measured in with the face work. Flagging and slabs of all kinds, such as hearths, treads for steps, etc., are measured by the square foot; sills, lintels, moldings, belt courses, and cornices, by the lineal foot, and irregular pieces are generally figured by the cubic foot. All carved work is done at an agreed price by the piece.

METHODS OF ESTIMATING MASONRY.

The following proportions and cost of materials, and amount of labor required for the classes of work below specified, are reasonably accurate, and will serve to give a good idea of how to estimate such work.

Cost of Rubble Masonry per Perch.

Using 1-to-3 Lime Mortar.

1 perch stone (25 cu. ft.) delivered at work	$1.25
1 bu. lime	.25
$\frac{1}{6}$ load of sand, at $1.50 per load	.25
$\frac{1}{3}$ day mason's labor, at $2.50 per day	.83
$\frac{1}{4}$ day helper's labor, at $1.50 per day	.38
Total	$2.96

Using 1-to-3 Portland Cement Mortar.

1 perch stone	$1.25
$\frac{1}{2}$ bbl. Portland cement, at $2.60 per bbl.	1.30
$\frac{1}{6}$ load sand, at $1.50 per load	.25
$\frac{1}{3}$ day mason's labor, at $2.50 per day	.83
$\frac{1}{4}$ day helper's labor, at $1.50 per day	.38
Total	$4.01

Using 1-to-3 Rosendale Cement Mortar.

1 perch stone	$1.25
½ bbl. Rosendale cement, at $1.25 per bbl.	.63
⅙ load sand, at $1.50 per load	.25
⅓ day mason's labor, at $2.50 per day	.83
¼ day helper's labor, at $1.50 per day	.38
Total	$3.34

Cost of 1 Square Foot of Ashlar.

Cost of stone, bluestone facing	$ .30
Hauling stone, say $\frac{1}{10}$ of cost of stone	.03
Mortar	.01
Labor, estimating 80 sq. ft. per day for two masons and one laborer:	
2 masons, at $3.00 per day	.08
1 laborer, at $1.50 per day	.02
Cost per square foot	$ .44

Cost of 1 Cubic Yard of Concrete.

1 bbl. of Rosendale cement, at $1.25 per bbl.	$1.25
3 bbl. of sand, or ⅓ load, at $1.50 per load	.50
1 cu. yd. (about 6 bbl.) of broken stone, at $1.50 per cu. yd.	1.50
Mason, ¼ day, at $2.50	.63
Laborer, 1 day, at $1.50	1.50
Total	$5.38

Cost of 1 Square Yard of Cellar Floor.

Concrete, 4½ in. thick, at $5.38 per cu. yd.	$ .67
Sand bed, 6 in. thick, approximately 1 bbl.	.17
Spreading sand	.02
$\frac{1}{12}$ bbl. of Portland cement for ½″ finishing coat, at $2.60 per bbl.	.22
$\frac{1}{12}$ bbl. of white sand, at $1.00 per bbl.	.08
Mixing and spreading surface layer	.08
Cost per square yard	$1.24

DATA ON ASHLAR AND CUT STONE.

Cost.—The following figures are average prices of stone when the transportation charges are not excessive; the figures are not given as fixed values, but to show the relative costs. They are based on quarrymen's wages of $2.25 per day, and stone cutters' of $3.00 per day.

First-class rock-face bluestone ashlar, with from 6″ to 10″ beds, dressed about 3 in. from face, will cost, ready for laying, from 35 to 45 cents per square foot, face measure; while very good work will cost from 25 to 40 cents per square foot. Regular coursed bluestone ashlar, 12 to 18 in. high, with from 8″ to 12″ beds, will cost about 50 cents per square foot. To this (and the previous figures) must be added the cost of hauling, which on an average will be about 2 cents per square foot. The cost of setting ashlar may be taken at about 10 cents per square foot.

The rough stock for dimension stone will cost, at the quarry, if Quincy granite, in pieces of a cubic yard, or less, from 50 to 75 cents per cubic foot; if bluestone, about 50 cents; if Ohio sandstone, about 30 cents per cubic foot; if Indiana limestone, about 25 cents per cubic foot; and if Lake Superior red stone, about 40 cents per cubic foot.

Flagstones for sidewalks. ordinary stock, natural surface, 3 in. thick, with joints pitched to line, in lengths (along walk) from 3 to 5 ft., will cost, for 3′ walk, about 8 cents per square foot (if 2 in. thick. 6 cents); for 4′ walk, 9 cents; and for 5′ walk, 10 cents per square foot. The cost of laying all sizes will average about 3 cents per square foot. The above figures do not include cost of hauling.

Curbing (4″ × 24″ granite) will cost, at quarry, from 25 to 30 cents per lineal foot; digging and setting will cost from 10 to 12 cents additional; and the cost of freight and hauling must also be added.

The following figures show the approximate cost of cut bluestone for various uses:

Flagstone, 5″, size 8 ft. × 10 ft., edges and top bush-hammered, per sq. ft., face measure	$ .65
Flagstone, 4″, size 5 ft. × 5 ft., select stock, edges clean cut, natural top, per sq. ft.	.30

Door sills, 8 in. × 12 in., clean cut, per lineal foot	$1.25
Window sills, 5 in. × 12 in., clean cut, per lineal foot	.80
Window sills, 4 in. × 8 in., clean cut, per lineal foot	.45
Window sills, 5 in. × 8 in., clean cut, per lineal foot	.60
Lintels, 4 in. × 10 in., clean cut, per lineal foot	.60
Lintels, 8 in. × 12 in., clean cut, per lineal foot	1.10
Water-table, 8 in. × 12 in., clean cut, per lineal foot	1.25
Coping, 4 in. × 21 in., clean cut, per lineal foot	1.10
Coping, 4 in. × 21 in., rock-face edges and top, per lin. ft.	.45
Coping, 3 in. × 15 in., rock-face edges and top, per lin. ft.	.25
Coping, 3 in. × 18 in., rock-face edges and top, per lin. ft.	.30
Steps, sawed stock, 7 in. × 14 in., per lineal foot	.90
Platform, 6 in. thick, per square foot	.45

To the prices of cut stone above given must be added the cost of setting, which, for water-tables, steps, etc., will be about 10 cents per lineal foot, and, for window sills, etc., about 5 cents per lineal foot. In addition, allow about 10 cents per cubic foot for fitting, and about 5 cents per cubic foot for trimming the joints after the pieces are set in place.

A stone cutter can cut about 6 sq. ft. of granite per day, 8 sq. ft. of bluestone, and about 10 sq. ft. of Ohio sandstone or Indiana limestone. These figures are for 8-cut patent-hammered work. For rock-face ashlar (beds worked about 3 in. from face, the rest pitched), a workman can dress from 25 to 28 sq. ft. of random ashlar per day, and from 18 to 20 sq. ft. of coursed ashlar. In dressing laminated stone, from 2 to 3 times more work in a day can be done on the natural surface than on the edge of layers. In figuring cut stone, an ample allowance should be made for waste, which, on an average, will be 25 per cent.

BRICKWORK.

Brickwork is generally estimated by the thousand brick laid in the wall, but measurements by the cubic yard and by the perch are also used. The following data will be useful in calculating the number of brick in a wall. For each superficial foot of wall, 4 in. (the width of 1 brick) in thickness, allow 7½ brick; for a 9″ (the width of 2 brick) wall,

allow 15 brick; for a 13″ (the width of 3 brick) wall, allow $22\frac{1}{2}$ brick; and so on, estimating $7\frac{1}{2}$ brick for each additional 4 in. in thickness of wall. The above figures are for the ordinary Eastern standard brick, which is about $8\frac{1}{4} \times 4 \times 2\frac{1}{4}$ in. in dimensions. If smaller brick are used, the figures will be increased proportionately. As brick vary considerably, a minimum size should be specified, when a large number are bought; otherwise, many more will be required than were figured on. If brickwork is estimated by the cubic yard, allow 500 brick to a yard. This figure is based on the use of the size of brick given above, with mortar joints not over $\frac{3}{8}$ in. thick. If the joints are $\frac{1}{8}$ in. thick, as in face brickwork, 1 cu. yd. will require about 575 brick. In making calculations of the number of brick required, an allowance of, say, 5 per cent. should be made for waste in breakage, etc.

The practice in regard to deductions for openings is not uniform throughout the country, but small openings are usually counted solid, as the cost of extra labor and the waste in working around these places balances that of the brickwork saved. All large openings, 100 sq. ft. or over in area, should be deducted.

When openings are measured solid, it is not usual to allow extra compensation for arches, pilasters, corbels, etc. Rubbed and ornamental brickwork should be measured separately, and charged for at a special rate.

Brick footings may be computed by the lineal foot. The following table, based on steps or offsets of one-quarter brick, or 2 in., for each course in the footing, gives the number of brick per lineal foot in footings for brick walls from 9 to 26 in. thick:

9″ wall, footing 2 courses, $10\frac{1}{2}$.	18″ wall, footing 4 courses, 39.
13″ wall, footing 3 courses, $22\frac{1}{2}$.	22″ wall, footing 5 courses, 60.
26″ wall, footing 6 courses, $85\frac{1}{2}$.	

DATA ON BRICKWORK.

The following estimates on the cost of brickwork are very carefully compiled, and will be found trustworthy. It is to be understood that the prices will vary with the cost of materials and labor; but the proportions will be constant.

The figures are based on *kiln*, or actual, count—that is, with deductions for openings. When the work is measured with no deductions for openings, the cost per thousand may be assumed as about 15 per cent. less than the prices given, which are exclusive of builder's profit.

Cost of Common Brickwork per Thousand Brick.

Using 1-to-3 Lime Mortar.

1,000 brick	$ 6.00
3 bu. lump lime at $.25 per bu	.75
½ load sand (½ cubic yard) at $1.50 per load	.75
7 hours, bricklayer, at $.35 per hour	2.45
7 hours, laborer, at $.15 per hour	1.05
Total	$11.00

Using 1-to-3 Portland Cement Mortar.

1,000 brick	$ 6.00
1½ bbl. Portland cement, at $2.60 per bbl.	3.90
½ load sand, at $1.50 per load	.75
7 hours, bricklayer, at $.35 per hour	2.45
7 hours, laborer, at $.15 per hour	1.05
Total	$14.15

Using 1-to-4 Lime-and-Cement Mortar.

1,000 brick	$ 6.00
3 bu. lime, at $.25 per bu	.75
½ load sand	.75
1 bbl. cement	2.60
7 hours, bricklayer, at $.35 per hour	2.45
7 hours, laborer, at $.15 per hour	1.05
Total	$13.60

Using 1-to-3 Rosendale Cement Mortar.

1,000 brick	$ 6.00
1½ bbl. Rosendale cement, at $1.25 per bbl	1.87
½ load sand	.75
7 hours, bricklayer, at $.35 per hour	2.45
7 hours, laborer, at $.15 per hour	1.05
Total	$12.12

COST OF PRESSED BRICKWORK PER THOUSAND BRICK.

Using Lime Putty Mortar.

1,000 pressed brick, cost from \$20.00 to \$40.00, average	\$30.00
$1\frac{1}{2}$ bu. lime	.38
$\frac{1}{4}$ load fine sand	.37
30 hours, bricklayer, at \$.40 per hour	12.00
15 hours, laborer, at \$.15 per hour	2.25
Total	\$45.00

CARPENTRY.

ESTIMATING QUANTITIES.

Board Measure.—The rough lumber used in framing is measured by the board foot, which means a piece 12 in. square and 1 in. thick. Lumber is always sold on a basis of 1,000 feet board measure; the customary abbreviation for the latter term is B. M., and for thousand is M; thus, 500 ft. board measure, costing \$14.00 per thousand, would be written: 500 ft. B. M. at \$14.00 per M.

To obtain the number of board feet in any piece of timber, the length of the scantling in inches may be multiplied by the end area in sq. in., and the result divided by 144. For example, the number of feet B. M. in a floor joist 20 ft. long, 3 in. thick, and 10 in. deep, will be 240 in. (= 20 ft. × 12) multiplied by 30 sq. in. (the end area), or 7,200 sq. in., 1 in. thick; dividing by 144, the result is 50 ft. B. M.

The rule used by most contractors and lumber dealers is as follows: *Multiply the length in feet by the thickness and width in inches, and divide the product by 12.* Thus, a scantling 26 ft. long, 2 in. thick, and 6 in. wide, contains

$$\frac{26 \times 2 \times 6}{12} = 26 \text{ ft. B. M.}$$

This rule, expressed in a slightly different manner more convenient for mental computation, is: *Divide the product of the width and thickness in inches by 12, and multiply the quotient by the length in feet.* Thus, a $2'' \times 10''$ plank, 18 ft. long, contains $\frac{2 \times 10}{12} \times 18 = 30$ ft. B. M.

Studs.—To calculate the number of studs, set on 16″ centers, the following rule may be used: *From the length of the partition deduct one-fourth, and to this result add 1. Count the number of returns, or corners, on the plan, and add two studs for each return.* (The reason for adding 1 is to include the stud at the end, which would otherwise be omitted.) The sills, plates, and double studs must be measured separately.

For example, the total number of studs required for the lengths of partitions given at the left is as follows:

30 ft. 6 in.
10 ft. 6 in.
9 ft. 6 in.
5 ft. 0 in.
4 ft. 6 in.
60 ft. 0 in.

Deducting one-quarter of 60 ft. from it, the remainder is 45; adding 1 stud, the result is 46. If there are, say, 4 returns, at 2 studs each, the total number is $46 + 8 = 54$ studs.

As a general rule, when (as is usual) the studs are set at 16″ centers, *1 stud for each foot in length* of partition will be a sufficient allowance to include sills, plates, and double studs. Thus, if the total length of partitions is 75 ft., 75 studs will be sufficient for sills, double studs, etc. If the studs are set at 12″ centers, *the number required will be equal to the number of feet in length of partition plus one-fourth.* Thus, if the length of partitions is 72 ft., $72 + 18$, or 90 studs, will include those required for sills, plates, etc.

The same rules may be used for calculating the number of joists, rafters, tie-beams, etc.

A good way to estimate bridging is to allow 2 cents apiece, or 4 cents a pair; this will be sufficient to furnish and set a pair made of $2'' \times 3''$ spruce or hemlock stuff.

Sheathing.—To calculate sheathing or rough flooring (which is not matched), find the number of feet B. M. required to cover the surface, making no deductions for door or window openings, for what is gained in openings is lost in waste. If the sheathing is laid horizontally, only the actual measurement is necessary, but, if it is *laid diagonally, add 8* or *10 per cent.* to the actual area.

In sheathing roofs where many hips, valleys, roof dormers, etc. occur, there will be a great deal of waste material caused by mitering the boards, fitting around cheeks of dormers

and forming saddles behind chimneys. This waste is not readily calculated and must be determined by the actual conditions as well as by the care exercised by the men in utilizing the cuttings. In covering large areas a great deal of material can be saved by ordering the lengths of boards to suit the spacing of the rafters.

Flooring.—In estimating matched flooring, a square foot of $\frac{7}{8}''$ stuff is considered to be 1 ft. B. M. If the flooring is 3 in. or more in width, *add one-quarter* to the actual number of board feet, to allow for waste of material in forming the tongue and groove; if less than 3 in. wide, *add one-third.* Flooring of $1\frac{1}{8}$ in., finished thickness, is considered to be $1\frac{1}{4}$ in. thick; and for calculating it the following rule may be used: *Increase the surface measure 50 per cent.* (This consists of 25 per cent. for extra thickness over 1 in., and 25 per cent. for waste in tonguing and grooving.) To this amount add 5 per cent. for waste in handling and fitting.

In figuring the area of floors, the openings for stairs, fireplaces, etc. should be deducted.

Siding.—Siding is usually measured by the superficial foot. No deduction should be made for ordinary window or door openings, as these usually balance the waste in cutting and fitting. Careful attention must be given to the allowance for lap. If $6''$ (nominal width, actual width $5\frac{5}{8}$ in.) siding, laid with $1''$ lap, is used, *add one-quarter* to the actual area, in order to obtain the number of square feet of siding required. If $4''$ stuff is used, *add one-third* to the actual area. When, as above noted, no allowance is made for openings, the corner and baseboards need not be figured separately.

Cornices.—Cornices may be measured by the running foot, the molded and plain members being taken separately. A good method of figuring cornices is as follows: *Measure the girth, or outline, and allow 1 cent for each inch of girth, per lineal foot.* This price will pay for material and for setting, the cost of the mill work being estimated at 50 per cent., or $\frac{1}{2}$ cent.

Quantity of Material Set per Day.—It is impossible to estimate this exactly, as it depends on the skill of the artisan, his rapidity of working, the ease or difficulty of the work,

besides numerous accidental circumstances. The subjoined figures, while founded on knowledge gained in many years' experience, are only intended to give an idea of the relative quantities, and not as a standard to be adhered to in all cases. The estimates are based on a 9-hour day, and wages of $2.25 per day. If the hours or pay be less or greater, the results will be correspondingly diminished or increased. Unless otherwise noted, the figures represent the labor of two men working together.

QUANTITIES OF MATERIAL PUT IN PLACE PER DAY.

Class of Material.	Feet B. M. or Number.	Remarks.
Studding, 2″×4″ or 2″×6″	600–800	Wall or Partition.
Rafters	500–600	
Floor joists, 2″×10″ or 3″×12″	1,500	
Sheathing, unmatched	1,000	Laid horizontally.
Sheathing, unmatched	800	Laid diagonally.
Sheathing, matched	800	Laid horizontally.
Sheathing, matched	600	Laid diagonally.
Sheathing, roof	1,000	Plain gable roof.
Sheathing, roof	500	Much cut up by hips, valleys, dormers, etc.
Siding	700	Includes fitting and setting corner boards, base, trim, and scaffolding.
Posts and beams over cellars	400–500	Includes scarfing and doweling.
Plaster grounds, lineal feet, per man	400	For base and wainscot, leveled and straightened in good shape.
Bridging, number of pairs, per hour, per man	12	Includes cutting and setting.
False jambs around openings, per hour, per man	1	

Nails.—To calculate the quantity of nails required in executing any portion of the work, the following table, based on the use of cut nails, will be found useful:

TABLE FOR ESTIMATING QUANTITY OF NAILS.

Material.	Pounds Required.	Name of Nail.
1,000 shingles	5	4d.
1,000 laths	7	3d.
1,000 sq. ft. of beveled siding	18	6d.
1,000 sq. ft. of sheathing	20	8d.
1,000 sq. ft. of sheathing	25	10d.
1,000 sq. ft. of flooring	30	8d.
1,000 sq. ft. of flooring	40	10d.
1,000 sq. ft. of studding	15	10d.
1,000 sq. ft. of studding	5	20d.
1,000 sq. ft. of furring 1″ × 2″	10	10d.
1,000 sq. ft. $\frac{7}{8}$″ finished flooring	20	8d. to 10d. finish
1,000 sq. ft. $1\frac{1}{8}$″ finished flooring	30	10d. finish

ESTIMATING COSTS

The character of the work, which must be determined by the spirit and letter of the specifications, will be the controlling factor in fixing costs. In the case of material, where the requirements are exacting and demand a grade of material which can only be obtained by special selection, an extra rate must always be considered. This is best secured by contracting with the lumber merchants for the supply of the material to strictly accord with the architect's stipulation. The matter of labor, however, is one on which too much care and forethought cannot be expended. What may be considered satisfactory work by one contractor would be considered inferior by another, and this often accounts for the great differences in estimates.

Cost per Square Foot.—For all classes of materials that enter into the general framing and covering of a building, a close estimate may be made by analyzing the cost per square foot of surface; that is, the cost of labor and materials—studs and sheathing in walls, joists and flooring in floors, etc.—required for a definite area should be closely determined, and this cost, divided by the area considered, will give the price per square foot. If the corresponding whole area is multiplied by the figure thus obtained, the result will, of course, be the cost of that portion of the work. While it is

usual to adopt a uniform rate for the various grades of work, a careful analysis will show that roof sheathing in place costs more than wall sheathing, owing to its position; and that the studs in walls and partitions cost more than floor joists, as they are lighter and require more handling.

The following example shows how to determine the cost per square foot of flooring, and indicates the general method to be pursued in like cases. The area used in calculation is a square of 100 sq. ft. The cost of labor is estimated at 50 per cent. of that of the materials, which experience has shown to be a very close approximation to the actual cost of general carpenter work.

COST OF FINISHED FLOOR PER SQUARE.

Joists, hemlock, 8 pieces, 3 in. × 10 in. × 10 ft. = 200 ft. B. M. at $14.00 per M	$ 2.80
Bridging, hemlock, 7 sets, 2 in. × 3 in. × 1. ft. 4 in. = 9 ft. B. M. at $14.00 per M	.13
Rough flooring, hemlock, $\frac{7}{8}$ in. thick, laid diagonally, 100 ft. + 25 ft. + 10 ft. = 135 ft. B. M. at $17.00 per M	2.29
Finished flooring, white pine, $\frac{7}{8}$ in. thick, 125 ft. B. M. at $22.00 per M	2.75
Nails, about 3 lb. at $1.80 per 100 lb.	.05
Labor, 50 per cent. of cost of materials	3.99
Total cost for 100 sq. ft.	$12.01

Cost per square foot, $12.01 ÷ 100 = 12 cents.

A similar method may be followed in estimating the cost of interior finish, paneling, doors, etc.

Cost per Thousand Feet.—The following analysis shows the general method of estimating rough carpenter work:

COST OF 1,000 FT. B. M. OF HEMLOCK.
Including Framing.

1,000 ft. of hemlock	$14.00
Nails and spikes, allowing 100 lb. to 3,000 ft. of lumber, at $1.80 per 100 lb.	.60
Labor, taking 50 per cent. of the cost of material as cost of framing	7.00
Cost per thousand feet B. M.	$21.60

COST OF MISCELLANEOUS ITEMS OF CARPENTRY.

Class of Work.	Cost.	Remarks.
Setting window frames in wooden buildings..........	$ .30	Each; about 1 hour required.
Furring brick walls 1″ × 2″ strips, 12″ centers.......	.02½	Per sq. ft.; includes labor, material, and nails.
Furring brick walls, 1″ × 2″ strips, 16″ centers......	.01⅞	Per sq. ft.
Cutting holes and fitting plugs in brick walls, 12″ centers	.02	Per sq. ft.
Cutting holes and fitting plugs in brick walls, 16″ centers	.01¾	Per sq. ft.
Setting window frames in brickwork.....................	.50	Each; includes nails and bracing.
Door frames in brickwork	.50	Each.
Window frames in stonework	1.25	Each; for ordinary work, screeded and bedded.
Window frames in stonework	2.00	Each; for careful work.
Door frames in stonework	2.00	Each; for very careful work.
Furnishing and setting trimmer-arch centers...	1.25	Each.
Arch centers, 3½-ft. span, 8″ reveal........................	1.00	Each; includes supports and wedges.

JOINERY.

Joinery includes all the interior and exterior finish put in place after the framing and the covering are completed; as, for example, door and window frames, doors, baseboard, paneling, wainscoting, stairs, etc. Most of these materials are worked at the mill and brought to the building ready to set in place.

Frames.—In taking off door and window frames, describe and state sizes. Measure architraves by the running foot, giving width and thickness, whether molded or plain, and state the number of plinth and corner blocks.

Sash.—State dimensions (giving the width first); thickness of the material, molded or plain; style of check-rail and sill

finish; thickness of sash bar, whether plain, single, or double hung; and sizes (giving dimensions in inches) and number of lights. Use standard sizes as much as possible.

Doors.—Describe and state the sizes and thickness, whether the framing is stuck-molded, raised-molded, or plain; and number of panels, whether plain or raised. Use stock sizes wherever possible and suitable.

Blinds.—Describe size and thickness, whether paneled or slatted (fixed or movable), and whether molded or plain.

Baseboard and Beam Casings.—Measure by the running foot, stating width and thickness of stuff, and whether molded or plain.

Wainscoting.—Measure by the superficial foot. State kind of finish, whether paneled or plain, and style of molding and panels. Measure wainscoting cap and base by the running foot.

Stairways.—They are generally taken by the contractor at so much per step, including everything complete according to the specifications. In measuring stairways, take off the amount of rough material in carriage timbers, and the planed lumber in treads, risers, and strings. Measure *balustrades* by the lineal foot. Give the size of *newels* and the style of treatment. Measure *spandrel* and *stairway paneling* the same as wainscoting.

Fixtures.—*Kitchen dressers* may be taken at a fixed price complete, or at a fixed rate per square foot, or as dressed lumber—drawers and doors being taken separately. *Wardrobes*, *bookcases*, *mantels*, and *china closets* should be treated separately, and a fixed price stated. *Porches*, *exterior balustrades*, *balconies*, *porte-cocheres*, etc., may be taken at a price per lineal foot, or the actual quantity of material may be measured.

DATA AND EXAMPLES OF ESTIMATING JOINERY WORK.

For any molded work which goes through the mill, the usual charge is *1 cent per square inch of section per lineal foot* of the stuff from which the molding is made, as a base, from which is deducted a percentage, usually 40 to 60 per cent., depending on the grade of the material. For example, a $\frac{7}{8}''$

(undressed thickness, 1 in.) door casing, 5 in. wide, will cost 1 cent × 5, less, say 50 per cent., or $2\frac{1}{2}$ cents per lineal foot.

Baseboard.—The cost of material and fitting in place may be estimated at *1 cent per square inch of section per lineal foot.* This is for pine; if hardwood is used, double this price.

The same rule applies also to *chair rails*, *cap rails*, and natural-finish *picture molds.*

Paneling.—This may be estimated at *12 cents per square foot* for 1-inch pine stuff; if over 1 in., add simply for extra material. If the paneling is of hardwood and veneered, add 50 per cent. to price of pine.

Wainscoting.—If plain, this may be estimated at *$6\frac{1}{2}$ cents per square foot,* the cap being figured separately by the lineal foot.

Door Frames.—The following estimate represents the approximate cost of an ordinary door frame. This and succeeding estimates are given more to show how to make systematic and accurate estimates than to give any fixed prices.

COST OF DOOR FRAME IN PLACE.

Size, 2 ft. 8 in. × 6 ft. 8 in.

Jambs (rabbeted for doors), 13 ft. 6 in.; head jamb, 3 ft.; total jambs, $16\frac{1}{2}$ ft. of $1\frac{1}{8}''$ $(1\frac{1}{4}'')$ × 6″ clear face material, at 1 cent per sq. in. per ft., less 50 per cent.	$0.62
Casing, $34\frac{1}{2}$ ft. of $\frac{7}{8}''$ (1″) × 5″, with $\frac{1}{4}$-round edge mold, at same rate	.8625
Back-band molding, $34\frac{1}{2}$ ft. of $\frac{7}{8}''$ (1″) × 2″ at same rate as casing	.345
Plinth blocks, 4 pieces, 9″ × $1\frac{3}{4}''$ (2″) × $5\frac{1}{4}''$ at 1 cent per sq. in. per ft., less 50 per cent	.1575
Dadoing and hand-smoothing casing, back band, and plinth blocks	.50
Nails	.05
Putting together and setting up ($2\frac{1}{2}$ hours)	.65
Cost in place	$3.18

Doors.—The subjoined estimate gives the cost of a door of moderate price. If the door is veneered with hardwood, the cost is about 50 per cent. additional. A curved door in a curved wall costs about twice as much as straight work.

Cost of Door in Place.

Size, 2 ft. 8 in. × 6 ft. 8 in.

$1\frac{3}{8}$ in. thick, 5-panel, double face, flat-paneled, and stuck- or solid-molded door, delivered	$2.00
Fitting hinges and lock, hanging and trimming	.50
Butts, 1 pair 4″ × 4″ lacquered steel	.40
Mortise lock, brass face and strike, wood knob, bronze escutcheons	.80
Cost in place	$3.70

A fair workman can hang, trim, and put hardware on, including mortise locks, about 6 ordinary doors per day. For veneered doors, or those requiring extra care, not more than 3 can be put in place.

Window Frames.—The following estimate gives approximately the cost of a window frame of the size mentioned:

Cost of Window Frame in Place.

Size, 2 Lights, 28 in. × 28 in.

Jambs 12 ft., head jamb $3\frac{1}{2}$ ft., total $15\frac{1}{2}$ ft.; $15\frac{1}{2}$ ft. × $1\frac{1}{8}$ in. ($1\frac{1}{4}$) × 5 in., at 1 cent per sq. in. per ft., less 50 per cent.	$0.48
Sill, $3\frac{1}{2}$ ft. × $1\frac{1}{8}$ in. × $5\frac{3}{4}$ in., same rate	.13
Subsill, 4 ft. × $1\frac{7}{8}$ in. × 4 in., same rate	.16
Blind stop, $15\frac{1}{2}$ ft. × $\frac{7}{8}$ in. × 2 in.	.15
Parting strip, $14\frac{1}{2}$ ft. × $\frac{1}{2}$ in. × 1 in.	.04
Outside casing, $11\frac{1}{2}$ ft. × $1\frac{1}{8}$ in. × 5 in.	.36
Head jambs, 4 ft. × $1\frac{1}{8}$ in. × 7 in.	.17
Cap, 4 ft. × $1\frac{1}{8}$ in. × 3 in.	.08
Molding, $4\frac{1}{2}$ ft. of $1\frac{1}{2}$″	.03
Sill nosing, 4 ft. × $1\frac{1}{8}$ in. × 4 in.	.10
Apron, 4 ft. × $\frac{7}{8}$ in. × 5 in.	.10
Cove molding, 4 ft. of $\frac{7}{8}$″	.02
Casing, $16\frac{1}{2}$ ft. × $\frac{7}{8}$ in. × 5 in.	.41
Back band, $16\frac{1}{2}$ ft. × $1\frac{1}{8}$ in. × $1\frac{1}{8}$ in.	.12
Sash stop, $14\frac{1}{2}$ ft. × $\frac{1}{2}$ in. × $1\frac{1}{2}$ in.	.05
Labor for frame complete, with outside casing attached at mill, and for setting inside casing at building	1.00
Total cost	$3.40

Windows.—The cost of an ordinary window may be estimated as follows:

COST OF SASH IN PLACE.

Size, 2 Lights, 28 in. × 28 in.

Cost of 2 sashes $1\frac{3}{4}$ in. thick, at mill	$1.15
Glass, first-quality double-thick American, and setting	1.75
Sash weights, 35 lb., at 1 cent per lb.	.35
Cord for weights, $22\frac{1}{2}$ ft., at $\frac{1}{2}$ cent per ft.	.11
Sash lifts, 2	.05
Sash lock	.25
Hanging sash and putting on stops	.50
Cost in place	$4.16

For curved sash in curved walls, the cost is about twice that of straight work.

Stairs.—The cost per step for an ordinary stairway, constructed according to the following specifications, is about $3.00. For a better class of work, add about one-quarter to this price.

Length of step, 3 ft.; tread, Georgia pine; riser, white pine; open stringer, white pine; nosing and cove; dovetail balusters, square or turned; rail $2\frac{1}{2}$ in. × 3 in.; 6″ start newel, cherry; two 4″ square angle newels, with trimmed caps and pendants; simple easements; furred underneath for plastering; treads and risers tongued together, housed into wall stringers, wedged, glued, and blocked.

The material of such a stairway will cost about $1.84 per step. This rate includes landing facia and balustrade to finish on upper floor. The labor on the same, millwork, and setting in place, is about $1.16 per step. For example, for a stairs having 17 steps and landing balustrade (including return, about 14 ft.), the entire cost will be 17 × $3.00 = $51.00, of which $31.28 will represent cost of dressed lumber, including turned balusters and newels and worked rail, and $19.72 will represent cost of labor in housing stringers, cutting, mitering, and dovetailing steps, working easements, fitting and bolting rails, and erecting stairway in building.

Verandas.—For small dwellings, it has been found by experience that a veranda built on the following specifications will cost about $2.25 per lineal foot:

Width, 5 ft.; posts, turned, set 6 to 8 ft. on centers; floor timbers, 2 in. × 6 in.; flooring, $\frac{7}{8}''$ white pine, sound grade; rafters, 2 in. × 4 in. dressed; purlins, 2 in. × 4 in., set 2 ft. on centers; roof sheathing, $\frac{7}{8}''$ matched white pine; box frieze and angle mold; angle and face brackets; steps; no balustrade.

To include balustrade, with 2″ turned balusters, add about 60 cents per lineal foot.

For a veranda, built according to the following specifications, the cost will be $4.00 per lineal foot:

Width, 8 ft.; columns, 9″ turned; box pedestals; box cornice and gutter; level ceiling; roof timbers, 2 in. × 6 in.; roof covered with matched boards; a good grade of tin; floor timbers, 2 in. × 8 in.; floor, $1\frac{1}{4}''$ white pine, second grade, with white-lead joints; no balustrade.

Including balustrade, with $2\frac{1}{2}''$ turned balusters, rail and base to suit, add 80 cents per lineal foot.

Where a portion of the veranda is segmental or semicircular, a close approximation to the cost will result if the girth of the circular part is measured, and a rate fixed at twice that for straight work of the same length. This applies to veranda framing, roofing, casing, and balustrades.

ROOFING.

ROOF MENSURATION.

While the ordinary principles of mensuration are all that are necessary to calculate any roof area, yet the modern house, with its numerous gables and irregular surfaces, introduces complications which render some further explanation of roof measurement desirable. The most common error made in figuring roofs, and one which should be carefully guarded against, is that of using the apparent length of slopes, as shown by the plan or side elevation, instead of the true length, obtained from the end elevations.

The area of a plain gable roof, as shown in end and side elevations in (*a*), Fig. 1, is found by multiplying the length *gj* by the slope length *b d*, and further multiplying by 2, for both sides. The area of the gable is found by multiplying the width of the gable *a d* by the altitude *c b* and dividing by 2.

At (*b*) is shown the plan and the elevation of a hip roof, having a deck *z*. The pitch of the roof being the same on each side, the line *c d* shows the true length of the common rafter *l m*, *c e* being the height of the deck above *a d*. At (*c*) is shown the method of determining the true lengths of the hips, and the true size of one side of the roof. Let *a b c d* represent the same lines as the corresponding ones in (*b*).

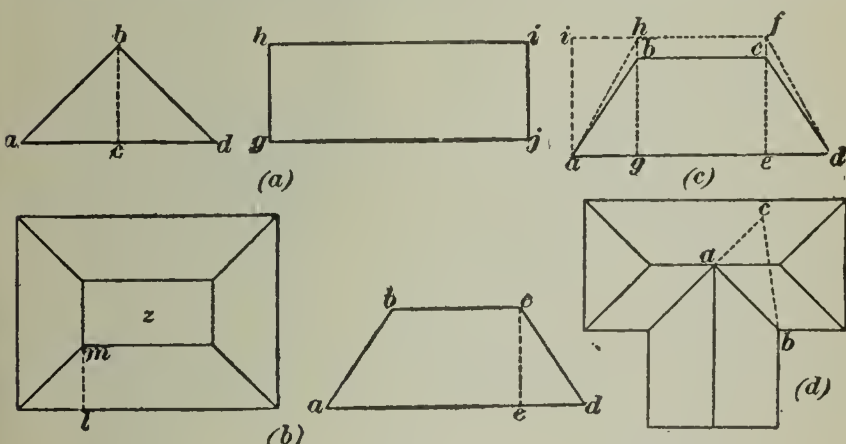


FIG. 1.

From the line *a d*, through *b* and *c*, draw perpendiculars, as *g h* and *e f*; lay off from *g* and *e* on these lines the length of the common rafter *a b*, in (*b*), and draw the lines *a h* and *d f*; then the figure *a h f d* will show the true shape and size of that side of the roof shown in the elevation in (*b*). The triangle *d e f* equals in area the triangle *a g h* or a similar triangle *a i h*. Hence, the portion of the roof *a h f d* is equal in area to the rectangle *a i f e*, whose length is one-half the sum of the eaves and deck lengths, and whose breadth is the length of a common rafter.

A method of obtaining the lengths of valley—applicable also to hip rafters—is shown at (*d*), which is the plan of a

hip-and-gable roof. To ascertain the length of the valley rafter $a\,b$, draw the line $a\,c$ perpendicular to $a\,b$ and equal in length to the altitude of the gable; then draw the line $c\,b$, which will be the length required.

As an example of roof mensuration, the number of square feet of surface on the roof shown in Fig. 2 will be calculated. The area of the triangular portion $a\,c\,b$ is equal to one-half the base $a\,b$, multiplied by the slope length of $c\,d$. The latter is found by making $c\,c'$, perpendicular to $d\,c$, equal to the

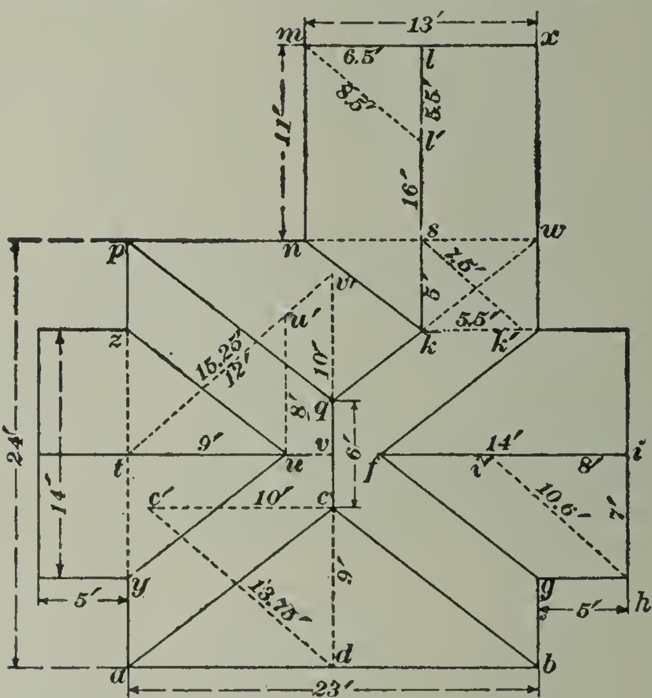


FIG. 2.

height of the ridge (10 ft.) above $a\,b$, and drawing $c'\,d$, which is the required slope length. Using dimensions, the area of $a\,c\,b$ is $\frac{23 \times 13.75}{2} = 158.1$ sq. ft.

The area of the trapezoid $g\,f\,i\,h$ is one-half the sum of $f\,i$ and $g\,h$, multiplied by the true length of $h\,i$, which, by laying off $i\,i'$, 8 ft. along $f\,i$, and drawing $i'\,h$, is found to be 10 ft. $7\frac{1}{2}$ in., or, say, 10.6 ft. Then $g\,f\,i\,h = \frac{14+5}{2} \times 10.6 = 100.7$ sq. ft.; or,

for the two slopes of the gable, the area is 201.4 sq. ft. As the opposite gable is the same size, the area of the two is $201.4 \times 2 = 402.8$ sq. ft.

The area of $q\,p\,n\,k$ is equal to the area $q\,p\,w$, minus the area $k\,n\,w$, which is covered by the intersecting gable roof. The area $q\,p\,w$ is equal to the area $a\,c\,b$, or 158.1 sq. ft. The area of $k\,n\,w$ is equal to $\frac{1}{2}$ the product of $n\,w$ and the slope of $s\,k$ (which, by laying off $k\,k'$ equal to the height of the gable, 5.5 ft., and drawing $s\,k'$, is found to be nearly 7.5 ft.). Then area $k\,n\,w = \frac{13 \times 7.5}{2} = 48.7$ sq. ft., which, deducted from 158.1 sq. ft., shows the area of $q\,p\,n\,k$ to be 109.4 sq. ft.

The area of $a\,p\,q\,c$ is $\frac{ap + qc}{2}$ multiplied by the true slope length of $t\,v$, which is $t\,v'$, measuring 15.25 ft. Substituting dimensions, the area is found to be $\frac{6 + 24}{2} \times 15.25 = 228.7$ sq. ft. From this deduct the area of $y\,z\,u$, which is the portion covered by the intersecting gable roof. The true length of $t\,u$ along the slope is $t\,u'$, which measures 12 ft.; hence, the area of $y\,z\,u$ is $\frac{14 \times 12}{2} = 84$ sq. ft. The net area of $a\,p\,q\,c$ is, therefore, $228.7 - 84 = 144.7$ sq. ft.; $b\,c\,q\,w$ being equal to $a\,p\,q\,c$, its area is the same, making the area of both sides 289.4 sq. ft.

The area of $k\,n\,m\,l$ is $\frac{m\,n + l\,k}{2} \times m\,l'$, the slope length of $m\,l$. Substituting dimensions, the area is $\frac{11 + 16}{2} \times 8.5 = 114.7$ sq. ft. As $k\,l\,x\,w$ is equal to $k\,n\,m\,l$, the area of both is 229.4 sq. ft. Adding the partial areas thus obtained, the sum is $158.1 + 402.8 + 109.4 + 289.4 + 229.4 = 1{,}189.1$ sq. ft., or 11.9 squares.

SHINGLES.

Measurement.—In measuring shingle roofing, it is necessary to know the exposed length of a shingle, which is found by deducting 3 inches—the usual cover of the upper shingle over the head of the third shingle below it—from the

length; dividing the remainder by 3, the result will be the exposed length; multiplying this by the average width of a shingle, the product will be the exposed area. Dividing 14,400, the number of square inches in a square, by the exposed area of 1 shingle, will give the number required to cover 100 sq. ft. of roof. For example, it is required to compute the number of shingles, 18 in. × 4 in., necessary to cover 100 sq. ft. of roof. With a shingle of this length, the exposure will be $\frac{18-3}{3} = 5$ in.; then the exposed area of 1 shingle is 4 in. × 5 in., or 20 sq. in., and 1 square requires $14,400 \div 20 = 720$ shingles.

In estimating the number of shingles required, an allowance should always be made for waste.

The following table is arranged for shingles from 16 to 27 in. in length, 4 and 6 in. in width, and for various lengths of exposure.

TABLE FOR ESTIMATING SHINGLES.

Exposure to Weather. Inches.	No. of Sq. Ft. of Roof Covered by 1,000 Shingles.		No. of Shingles Required for 100 Sq. Ft. of Roof.	
	4 In. Wide.	6 In. Wide.	4 In. Wide.	6 In. Wide.
4	111	167	900	600
5	139	208	720	480
6	167	250	600	400
7	194	291	514	343
8	222	333	450	300

Shingles are classed as *shaved* or *breasted*, and *sawed* shingles. The former vary from 18 to 30 in. in length, and are about $\frac{1}{2}$ in. thick at the butt and $\frac{1}{16}$ in. at the top; the latter are usually from 14 to 18 in. long, and of various thicknesses, five 18″ shingles, placed together, measuring $2\frac{1}{4}$ in. at the butt, the thickness of each at the top being $\frac{1}{16}$ in.

Strictly first-class shingles are generally given a brand of XXX, and those of a slightly poorer quality are termed

No. 2; but in some sections of the country, the brand A is general; thus, "choice A" or "standard A" are practically equivalent to the XXX shingles.

Shaved shingles are usually packed in bundles of 500, or 2 bundles per thousand. Sawed shingles are made up into bundles of 250, and are sold on a basis of 4 in. width for each shingle. If the wider ones are ordered, the cost per thousand is correspondingly increased. For example, if it requires 1,000 of 4″ shingles to cover a roof area, and 6″ ones were ordered, only two-thirds as many, or 667, would be needed and furnished, while the cost would be that of 1,000 standard-width shingles.

Shingles cost from $3.00 to $5.00 per thousand, according to material and grade. Dimension shingles—those cut to a uniform width—of prime cedar, shaved, ½ in. thick at the butt, and $\frac{1}{16}$ in. at the top, will cost $9.00 to $10.00 per thousand, but such shingles are usually 6 in. wide and 24 in. long, so that a less number will be required per square than of ordinary shingles.

A fairly good workman will lay about 1,500 shingles per day of 9 hours, on straight, plain work; while, in working around hips and valleys, the average will be about 1,000 per day.

Cost.—The method of estimating the cost of shingle roofing is as follows:

COST OF 1,000 SHINGLES IN PLACE.

Exclusive of Sheathing.

1,000 shingles XXX	$5.00
Labor: 1 man can lay 1,500 shingles per day; wages being $2.25, the cost per thousand is	1.50
Nails, about	.25
(Flashing, about 10 cents per sq. ft.)	
Cost per thousand, about	$6.75

SLATING.

Measurement.—In measuring slating, the method of determining the number of slates required per square is similar to that given for shingling; but, in slating, each course overlaps

only two of the courses below, instead of three, as in shingling. The usual lap, or cover of the lowest course of slate by the uppermost of the three overlapping courses, is 3 in.; hence, to find the exposed length, deduct the lap from the length of the slate, and divide the remainder by 2. The exposed area is the width of the slate multiplied by this exposed length, and the number required per square is found by dividing 14,400 by the exposed area of 1 slate.

Thus, if 14″ × 20″ slates are to be used, the exposed length will be $\frac{20-3}{2} = 8\frac{1}{2}$ in.; the exposed area will be $14 \times 8\frac{1}{2} = 119$ sq. in., and the number per square will be $14{,}400 \div 119 = 121$ slates.

The following rules should be observed in measuring slating: Eaves, hips, valleys, and cuttings against walls are measured extra, 1 ft. wide by their whole length, the extra charge being made for waste of material and the increased labor required in cutting and fitting. Openings less than 3 sq. ft. are not deducted, and all cuttings around them are measured extra. Extra charges are also made for borders, figures, and any change of color of the work, and for steeples, towers, and perpendicular surfaces.

The following table, based on 3″ lap, gives the sizes of the American slates, and the number of pieces required per square.

NUMBER OF SLATES PER SQUARE.

Size. Inches.	Number of Pieces.	Size. Inches.	Number of Pieces.	Size. Inches.	Number of Pieces.
6 × 12	533	9 × 16	246	14 × 20	121
7 × 12	457	10 × 16	221	11 × 22	138
8 × 12	400	9 × 18	213	12 × 22	126
9 × 12	355	10 × 18	192	13 × 22	116
7 × 14	374	11 × 18	174	14 × 22	108
8 × 14	327	12 × 18	160	12 × 24	114
9 × 14	291	10 × 20	169	13 × 24	105
10 × 14	261	11 × 20	154	14 × 24	98
8 × 16	277	12 × 20	141	16 × 24	86

Cost.—The cost of slating may be estimated as follows:

COST OF 1 SQUARE OF SLATING.

Slates, 8 in. × 12 in.	$5.00
Labor: 1 slater will average 2 squares per day; wages being $2.00 per day, 1 square will cost	1.00
Nails, 8″ × 12″ slates require 5 lb. 9 oz. (5.6 lb.) of galvanized nails per square, which, at $2.20 per 100 lb., cost.	.12
Roofing felt, 1 roll	2.40
Labor and nails for applying felt	.15
Flashing will cost about 10 cents per sq. ft.	
Cost per square	$8.67

This figure is exclusive of roof sheathing, the cost of which may be estimated as shown for hemlock framing, on page 340.

The cost of slating per square varies from 7 to 13 cents per sq. ft., depending on the class of work.

TIN ROOFS.

In estimating tin (and also other metal) roofs, hips and valleys are measured extra their entire length by 1 ft. in width, to compensate for increased labor and waste of material in cutting and laying. Gutters and conductor, or leader, pipes are measured by the lineal foot, 1 ft. extra being added for each angle. All flashings and crestings are measured by the lineal foot. For seams, addition is made to superficial area, depending on the kind of seam used, whether *single-lock*, *standing*, or *roll-and-cap*. No deductions are made for openings (chimneys, skylights, ventilators, or dormer-windows), if less than 50 sq. ft. in area; if between 50 and 100 sq. ft., one-half the area is deducted; if over 100 sq. ft. the whole opening is deducted. An extra charge is made for labor and waste of material to flash around such openings.

A box of roofing tin contains 112 sheets 14 in. × 20 in., and weighs from 110 to 140 lb. per box, according to whether it is *IC* or *IX* plate. The *IC* plate, which is the most used, weighs about 8 oz. per sq. ft., and the *IX*, about 10 oz. As there are considerable variations in the weights of tin made by different

manufacturers, a fair average will be obtained by estimating *IC* tin at 1 lb., and *IX* tin at $1\frac{1}{4}$ lb., per sheet. Double-size roofing tin can be had 20 in. × 28 in., weighing, if *IC*, 225 lb. per box. This size is the most economical, as by its use much material and labor are saved, on account of the less number of seams and ribs required.

A 14″ × 20″ sheet will cover about 235 sq in. of surface, using standing joints; or a box will cover about 182 sq. ft. With a flat-lock seam, a sheet will cover 255 sq. in., allowing $\frac{3}{8}$ in. all around for joints; or a box will lay 198 sq. ft. These figures make no allowance for waste.

Two good workmen can put on, and paint outside, from 250 to 300 sq. ft. of tin roofing per day of 8 hours. Tin roofing will cost from 8 to 10 cents per sq. ft., depending on the quality of material and workmanship.

TILE ROOFS.

Tile roofs are constructed of so many styles of tile that no general rules of measurement can be given, and every piece of work must be estimated according to the particular kind of tile used and the number of sizes and patterns. Information on all these points are to be found in the catalogues of tile manufacturers.

GRAVEL ROOFING.

In gravel roofing, the cost per square depends on the number of thicknesses of tarred felt and the quantity of pitch used per square.

PLASTERING.

Plastering on plain surfaces, such as walls and ceilings, is always measured by the square yard; but there are considerable variations in detail in the methods of measurement in different sections of the country. The following rules, however, probably represent the average practice, and are equitable to both parties concerned:

On walls and ceilings, measure the surface actually plastered, making no deduction for grounds or for openings of less extent than 7 superficial yards.

Returns of chimney breasts, pilasters, and all strips of plastering less than 12 in. in width, measure as 12 in. wide.

In closets, add one-half to the actual measurement; if shelves are put up before plastering, charge double measurement.

For raking ceilings or soffits of stairs, add one-half to measurement; for circular or elliptical work, charge two priees; for surfaees of domes or groined ceilings, charge three prices.

Round corncrs and arrises (other than chimney breasts) should be measured by the lineal foot.

On interior work, increase the price 5 per cent. for eaeh 12 ft. above the ground after the first. For outside work, add 1 per eent. for each foot above the lower 20 ft.

All repairing and patching should be done at agreed prices.

Stucco Work.—Cornices composed of plain members and panel work are measured by the square foot. Enriched eorniees, with carved moldings, are measured by the lineal foot. When moldings are less than 12 in. in girth, measurement is taken by the lineal foot; when over 12 in., superfieial measurement is used. For internal angles or miters, add 1 ft. to length of cornice; and for external angles, add 2 ft. to length. Sections of cornices less than 12 in. measure as 12 in. Add one-half for raking cornices.

For cornices or moldings abutted against wall or plain surface, add 1 ft. to length of cornice; if against soffit of stairs or other inelined or coved surfaee, add 2 ft. to length of corniec. Oetagonal, hexagonal, and similar cornices, less than 10 ft. in single stretches, measure one and one-half times the length.

For cireular or elliptical work, charge double priees; for domes and groins, charge three prices.

Column and pilaster capitals, frieze enrichments, and work of this charaeter, whieh require artistie treatment, are either made to eonform to the models furnished by the architect, or they are modeled from the architect's designs and submitted to him for approval. Expense of modeling is large; prices are usually obtained from specialists in this department.

ESTIMATES OF QUANTITIES AND COSTS.

Plastering.—Two plasterers and one laborer should average from 60 to 70 sq. yd. per day. The cost of labor on 3-coat work, costing about 25 cents per sq. yd., will be about 12 cents. For 2-coat work, costing about 20 cents per sq. yd., the cost of the labor will be about 8 cents. Both of these figures on labor are exclusive of the cost of lathing.

The following analyses of cost of 2- and 3-coat plastering are carefully made, and may be relied on as bases for estimates. Very fine work will cost considerably more.

Cost of 100 Sq. Yd. of 3-Coat Plastering.

1,440 laths, 1½ in. wide, ⅜″ spacing, at $2.10 per 1,000	$ 3.02
10 lb. 3d. nails, at $2.05 per 100 lb.	.20
Labor: putting on lath, 1 day	2.25
13 bu. of lime, at $.25 per bu.	3.25
1 bu. of hair, 8 lb., at $.04 per lb.	.32
1½ loads of plastering sand, at $1.50 per load	2.25
⅓ bbl. of plaster of Paris, at $1.50 per bbl.	.50
Labor:	
Plasterer, 3¼ days, at $3.00 per day	9.75
Helper, 2½ days, at $1.50 per day	3.75
Cartage	1.00
Total	$26.29

Cost per sq. yd., $26.29 ÷ 100 = 26 cents, approximately.

Cost of 100 Sq. Yd., 2-Coat Plastering.

Cost of lath and putting on, same as above	$ 5.47
10 bu. of lime, at $.25 per bu.	2.50
¾ bu., or 6 lb., of hair, at $.04 per lb.	.24
1 load of sand	1.50
⅓ bbl. plaster of Paris, at $1.50 per bbl.	.50
Labor:	
Plasterer, 2¼ days, at $3.00 per day	6.75
Helper, 2¼ days, at $1.50 per day	3.37
Cartage	1.00
Total	$21.33

Cost per square yard, $21.33 ÷ 100 = 21 cents, approximately.

Lathing.—This is measured by the superficial yard, no openings under 7 superficial yards being deducted.

Plastering laths are about $1\frac{1}{2}$ in. wide, $\frac{1}{4}$ in. thick, and usually 4 ft. long, the studding being generally placed 12 or 16 in. on centers, so that the ends of the lath may be nailed to them. The laths are usually set from $\frac{1}{4}$ to $\frac{3}{8}$ in. apart, requiring about $1\frac{3}{4}$ or $1\frac{1}{2}$ laths, 4 ft. long, to cover 1 sq. ft.

For a good average grade of work, a man will lay, on an average, about 15 bunches, or 1,500 laths per day, while a rapid workman will put on about 2,000 laths. The cost of nailing up laths will be from 18 to 25 cents per bunch, or $1.80 to $2.50 per thousand, being about equal to the cost of the laths and nails.

PAINTING AND PAPERING.

PAINTING.

Painting is measured by the superficial yard, girting every part of the work that is covered with paint, and allowing additions to the actual surface to compensate for the difficulty of covering deep quirks of moldings, for carved and enriched surfaces, etc. Ordinary door and window openings are usually measured solid, on account of the extra time taken in working around them, "cutting in" the window sash, etc. Porch and stair balustrades, iron railings, and work having numerous thin strips are also figured solid, for a like reason. Allowance is frequently made for distance from ground that the work is to be done, as in cornices, balconies, dormers, etc., and also for the difficulty of access.

Charges are usually made for each coat of paint put on, at a certain price per superficial yard and per coat.

Graining and marbling (imitations of wood and stone) and varnishing are rated at different prices from plain work.

Capitals and columns and other ornamental work, which are difficult to measure, should be enumerated, and a clear description of the amount of work on them should be given.

Quantities.—One pound of paint covers from $3\frac{1}{2}$ to 4 sq. yd. of wood first coat, and from $4\frac{1}{2}$ to 6 sq. yd. for each addi-

tional coat; on brickwork, it will cover about 3 and 4 sq. yd., respectively. Colored paint will cover about one-third more surface than white paint.

Using prepared or ready-mixed paint, 1 gal. will cover from 250 to 300 sq. ft. of wood surface, two coats; for covering metallic surfaces, 1 gal. will be sufficient for from 300 to 350 sq. ft., two coats. The weight per gallon of mixed paints varies considerably, but, on an average, may be taken at about 16 lb.

Prepared shingle stains will cover about 200 sq. ft. of surface, per gallon, if applied with a brush; or this quantity will be sufficient for dipping about 500 shingles. Rough-sawed shingles will require about 50 per cent. more stain than smooth ones.

One pound of *cold-water* paint will cover from 50 to 75 sq. ft. for first coat, on wood, according to surface condition, and about 40 sq. ft. of brick and stone.

One gallon of liquid pigment filler, hard oil finish or varnish, will generally cover from 350 to 450 sq. ft. of surface for first coat, according to the nature of wood and finish, and from 450 to 550 sq. ft. for the second and subsequent coats. Ten pounds of paste wood filler will cover about 400 sq. ft.

One gallon of varnish weighs from 8 to 9 lb.; turpentine, about 7 lb.; and boiled or raw linseed oil, about $7\frac{3}{4}$ lb.

For puttying, about 5 lb. will be sufficient for 100 sq. yd. of interior and exterior work.

For sizing, about $\frac{1}{2}$ lb. of glue is used to 1 gal. of water.

For mixing paints, the following figures represent the average proportions of materials required per 100 lb. of lead:

QUANTITIES OF MATERIALS.

Coat.	Lead. Lb.	Raw Oil. Gal.	Japan Drier. Gal.
Priming coat	100	7	$\frac{3}{4}$
Second coat	100	6	
Third coat............	100	$6\frac{1}{2}$–7	

The drier is omitted in the second and succeeding coats,

unless the work is to be dried very rapidly, as it is considered injurious to the durability of the paint.

On outside work, boiled oil is generally used in about the proportion of 3 gal. of boiled oil to 2 gal. of raw oil.

Cost.—The cost of applying paint, on general interior and exterior work, will average about twice the cost of the materials; while for very plain work, done in one color, the cost may be taken at about 1½ times that of the materials. For stippling, the cost will be about the same as for two coats of paint. For varnishing, the cost of labor will be about 1½ times the price of the varnish. The class of work demanded, however, will regulate the actual cost, as the rubbing down of the successive coats requires the expenditure of much time.

The following figures represent fair average prices, for various classes of work, and have been adopted by the Builders' Exchange of a large Eastern City:

INTERIOR WORK.	Cost per Square Yard.
1 coat paint, 1 color	$0.12
1 coat paint, 2 colors	.15
2 coats paint, 2 colors	.20
3 coats paint, 2 colors	.25
2 coats paint, 3 colors	.25
3 coats paint, 3 colors	.32
1 coat shellac	.10
Walls, 1 coat size, 2 coats paint	.20
Walls, 1 coat size, 3 coats paint, stipple	.30
Hardwood Finish.	
1 coat paste filler, 1 coat varnish	$0.30
1 coat paste filler, 2 coats varnish	.40
1 coat paste filler, 3 coats varnish	.50
Natural Finish.	
1 coat liquid filler, 1 coat varnish	$0.20
1 coat liquid filler, 2 coats varnish	.25
1 coat liquid filler, 3 coats varnish, rubbed	.40
Floors: filling, shellacing, varnishing, or waxing, 2 coats	.35

Tinting Walls.

Distemper Color.	Cost per Square Yard.
Tinting, 50 yards, or less	$0.09
Tinting, 50 yards, or more	.07
Patching and washing walls	.07

Exterior Painting.

Woodwork.

1 coat, new work	$0.10
2 coats, new work, 2 colors	.18
2 coats, new work, 3 colors	.20
3 coats, new work, 2 colors	.25
3 coats, new work, 3 colors	.28

Brickwork.

1 coat	$0.12
2 coats	.18
3 coats	.25

Sanding.

2 coats paint, 1 coat sand	$0.28
3 coats paint, 1 coat sand	.35
3 coats paint, 2 coats sand	.50

Miscellaneous.

Dipping shingles, per 1,000	$3.00
Additional coat, per 1,000	.50
Blinds, per foot, 1 coat	.08
Fence, per foot, 1 coat 4 feet high, wood	.12
Iron fence, per foot, 1 coat	.08
Tin roof, per yard, 1 coat	.05

PAPERING.

Papering is usually figured per roll, put on the wall. The paper is generally 18 in. wide, and is in either 8-yd. or 16-yd. rolls. On account of waste in matching, etc., it is difficult to estimate very closely the number of rolls required, but an approximate result may be obtained as follows: Divide the perimeter of the room by 1½ (the width of paper in feet); the

result will be the number of strips. Find the number of strips that can be cut from a roll, and divide the first result by the second; the quotient will be the number of rolls required. No openings less than 20 sq. ft. in area should be deducted, in order to compensate for cutting and fitting at such places. Add about 15 per cent. to the area to allow for waste. The border, whether wide or narrow, is usually figured as 1 roll of paper.

The cost of paper is extremely variable, ranging from 15 cents to $6.00 per double roll; the average cost is probably 20 to 25 cents per roll for ordinary houses. Paper hanging costs from 30 to 75 cents per double roll, with strips butted, the former figure being for the usual grade of work; with lapped strips, the cost is less, being from 20 to 25 cents per roll. Sometimes an extra charge is made for papering ceilings.

MISCELLANEOUS NOTES.

Plumbing.—An approximate figure for cost of plumbing is 10 per cent. of the cost of the building. This figure is for good materials and labor, and of course is subject to considerable variation. For an ordinary house, costing from $1,500 to $3,000, the cost of plumbing may be taken as about 8 per cent. for moderate-priced fixtures and public sewer service. The cost of labor alone will average about $\frac{1}{4}$ the cost of the materials.

Gas-Fitting.—The cost of gas-fitting may be approximately figured as about 3 per cent. of the cost of the building. The cost of labor alone varies from about $\frac{1}{4}$ to $\frac{1}{7}$ the cost of materials. The better the grade of fixtures, the lower will be the ratio—provided there is no excessive ornamentation, requiring much time to put in place—as the cost of the labor is about the same for cheap fixtures as for more costly ones.

Heating.—The cost of hot-air installation is, approximately, 5 per cent. of the cost of the building; for steam heating, 8 per cent.; for hot-water heating, 10 per cent.

In estimating on heating by furnace, the average cost of labor is about $\frac{1}{3}$ that of materials. In steam and hot-water heating, the ratio is about $\frac{1}{5}$.

Hardware.—Hardware is best estimated by noting the quantities required for each portion of the work as it is being measured, afterwards making these items into a separate hardware bill. Many of the articles, as, for example, the number of fixtures for doors or window trimmings, may be readily counted from the plans. Hardware for windows, doors, etc., are sometimes included in estimating the cost per window, door, etc., and are not considered separately. The cost of hardware depends entirely on the class of work and finish desired, and the best way to estimate on it is, after making the schedule, to select suitable designs and figure the prices from a catalogue. An approximate estimate for ordinary buildings is $1\frac{1}{2}$ per cent. of the cost of the building. From 15 to 20 per cent. of the cost of hardware will pay for the putting in place.

ELEMENTS OF ARCHITECTURAL DESIGN.

PROPORTIONS OF THE GREEK AND ROMAN ORDERS.

In proportioning the Greek and Roman orders, a uniform standard of measurement was adopted, so that the several parts of the order might be arranged in perfect ratio. This standard consists of *modules* and *parts*. A module is the semidiameter of the column, measured at the base, and each module is divided into 30 equal parts. Each diameter, therefore, is equal to 2 modules, or 60 parts.

THE GREEK ORDERS.

In Fig. 1 is shown a diagram of the Greek orders, after measured drawings by acknowledged authorities, drawn to a uniform altitude. *A* is an example of pure Doric, from the Portico of the Parthenon, at Athens. *B* is the Ionic, and is taken from the North Porch of the Erechtheum, while *C* is

the Corinthian, after the monument of Lysicrates. In each example *a* is the stylobate or base, *b* is the column, and *c* the entablature. The column of the Doric consists of a shaft and capital, the shaft resting directly on the stylobate, while the columns of the Ionic and Corinthian have a base, shaft, and capital. The entablature of each order has three divisions—the architrave, frieze, and cornice.

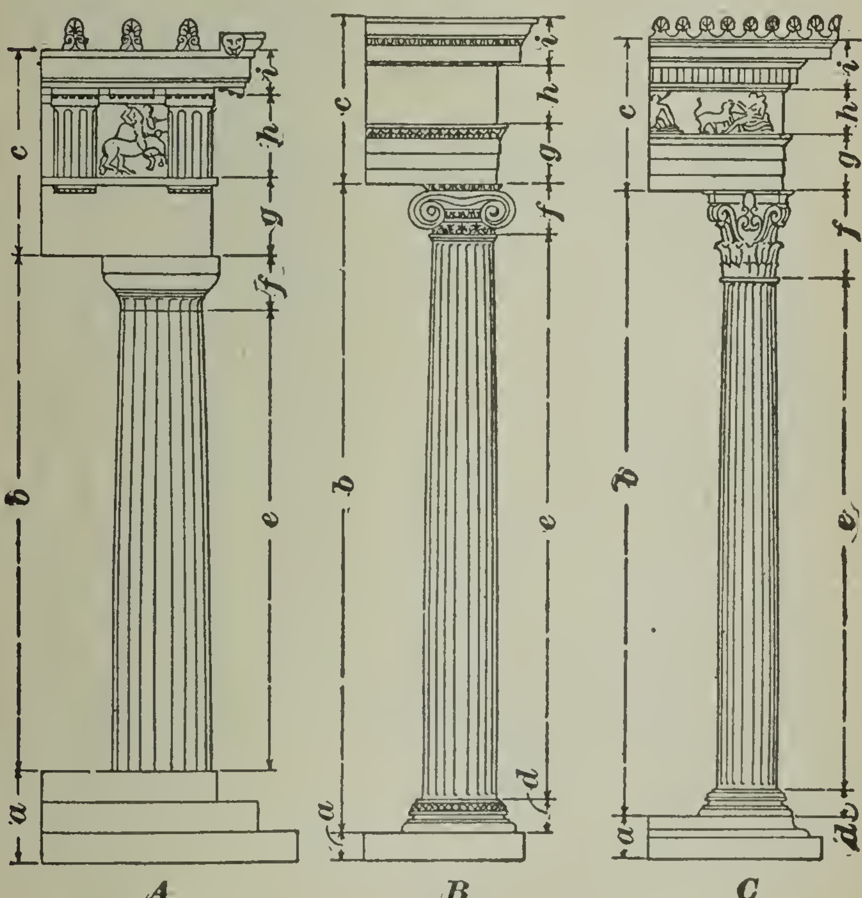


FIG. 1.

A comparative statement of the relative values of the divisions of each of the Greek orders is given in Table I, and is based on the module, or semi-diameter, as the unit of measurement; as previously explained, a part is $\frac{1}{30}$ of this unit.

TABLE I.

GREEK ORDERS.

Title.	Height of Column.								Height of Entablature.								Ratio of Entablature to Column.
	Base. *d*		Shaft. *e*		Cap. *f*		Total.		Arch. *g*		Frieze. *h*		Cornice. *i*		Total.		
	m.	p.	m.	p.	m.	p.	m.	p.	m.	p.	m.	p.	m.	p.	m.	p.	
Doric	0	0	10	$2\frac{3}{4}$	0	$27\frac{1}{4}$	11	0	1	$12\frac{2}{3}$	1	$12\frac{3}{5}$	*	23	3	$18\frac{4}{15}$	.328
Ionic	0	$23\frac{5}{6}$	15	$22\frac{5}{6}$	1	$13\frac{1}{3}$	18	0	1	$20\frac{3}{4}$	1	$17\frac{3}{4}$	1	$7\frac{3}{5}$	4	$16\frac{1}{10}$	.252
Corinthian	0	$22\frac{1}{3}$	16	$12\frac{1}{6}$	2	$25\frac{1}{2}$	20	0	1	$22\frac{1}{2}$	1	14	1	$18\frac{1}{2}$	4	25	.242

* Exclusive of the crowning member on the pediment, which is 9 parts high.

The Doric was largely used by the Greeks, their most important buildings being erected in this order. The proportions vary largely in the different examples, proceeding from extreme sturdiness in the early examples to the great refinement of the Parthenon, from which the figures of the table were taken. The architrave overhangs the face of the shaft, which is always fluted. The Ionic order was used with much delicacy by the Greeks. The distinctive capital has scrolls showing on two sides only, although examples of corner scrolls, adopted by the Romans, are also found. The Corinthian order was little used by the Greeks, but the few examples of this style, and especially the one here shown, are unsurpassed for elegance and beauty.

THE ROMAN ORDERS.

The Romans adopted the column and beam system of the Greeks, and joined to it the *arch* and *vault*. The union of the two elements of *arch* and *beam* is the keynote of the Roman style. In this style the orders were used more for decoration than for construction, and were *superposed*, or set one upon the other, dividing the buildings into stories.

The five Roman orders are shown in Fig. 2. *A* is the Tuscan; *B*, the Doric; *C*, the Ionic; *D*, the Corinthian; and *E*, the Composite. In each of these, a', b', and c' represent

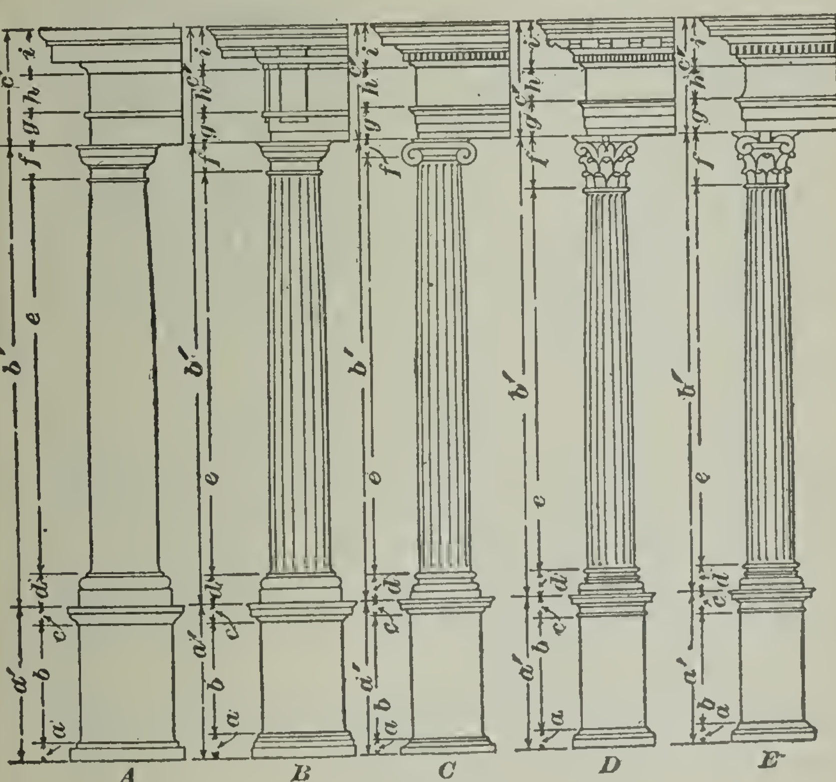


FIG. 2.

the pedestal, column, and entablature, respectively. For comparison, the relative values of the lower diameters of the shafts, when the orders are profiled to a uniform total height of 31 ft. 8 in., is given in Table II.

TABLE II.

ROMAN ORDERS.

With Uniform Altitude = 31 ft. 8 in.

Title.	Index Letter on Fig. 2.	Lower Diameter of Shaft.	
		With Pedestal.	Without Pedestal.
Tuscan	*A*	2 ft. $10\frac{1}{4}$ in.	3 ft. $7\frac{7}{16}$ in.
Doric	*B*	2 ft. 6 in.	3 ft. 2 in.
Ionic	*C*	2 ft. $2\frac{5}{8}$ in.	2 ft. $9\frac{3}{4}$ in.
Corinthian	*D*	2 ft. 0 in.	2 ft. $6\frac{3}{8}$ in.
Composite	*E*	2 ft. 0 in.	2 ft. $6\frac{3}{8}$ in.

Table III gives the relative measurements, with respect to the module, or semi-diameter of the shaft, for proportioning the Roman orders, and is valuable for consultation when preparing preliminary designs, the reference letters being those shown in Fig. 2.

NOTES.

In connection with the Roman orders it is well to keep in mind that the pedestal is one-third, and the entablature one-fourth, the height of the column in all cases.

To find the semi-diameter of the column in any order, divide the height to be occupied by the number of modules in the given order. Thus, if the given height is 23 ft. 9 in. and the order is the Ionic, *with* the pedestal, the semi-diameter, or module, will be 23 ft. 9 in. $\div 28\frac{1}{2} =$ 10 in.; if *without* the pedestal, the module will be 23 ft. 9 in. $\div 22\frac{1}{2}$ $= 12\frac{2}{3}$ in. The lower one-third of the columns is cylindrical, the upper two-thirds being diminished by a conchoidal curve called the *entasis*, the reduction of the shaft at the neck in all cases being one-sixth of the lower diameter.

In terms of the lower diameter, the Tuscan, Doric, Ionic, Corinthian, and Composite columns are respectively 7, 8, 9, 10, and 10 diameters high.

TABLE III
ROMAN ORDERS.

Title.	Index Letter on Fig. 2.	Height of Pedestal.								Height of Column.								Height of Entablature.								Altitude of Orders.			
		Base *a*.		Dado *b*.		Cornice *c*.		Total.		Base *d*.		Shaft *e*.		Cap *f*.		Total.		Arch. *g*.		Frieze *h*.		Cornice *i*.		Total.		With Pedestal.		Without Pedestal.	
		m	p	m	p	m	p	m	p	m	p	m	p	m	p	m	p	m	p	m	p	m	p	m	p	m	p	m	p
Tuscan	*A*	0	15	3	20	0	15	4	20	0	30	12	0	0	30	14	0	0	30	1	5	1	10	3	15	22	5	17	15
Doric	*B*	0	25	4	0	0	15	5	10	0	30	14	0	0	30	16	0	0	30	1	15	1	15	4	0	25	10	20	0
Ionic	*C*	0	$16\frac{2}{3}$	4	$26\frac{2}{3}$	0	$16\frac{2}{3}$	6	0	1	2	16	8	0	20	18	0	1	$7\frac{1}{2}$	1	15	1	$22\frac{1}{2}$	4	15	28	15	22	15
Corinthian...	*D*	0	25	5	0	0	25	6	20	1	$2\frac{1}{2}$	16	$17\frac{1}{2}$	2	10	20	0	1	15	1	15	2	0	5	0	31	20	25	0
Composite...	*E*	0	$21\frac{2}{3}$	5	$3\frac{1}{3}$	0	25	6	20	1	$2\frac{1}{2}$	16	$17\frac{1}{2}$	2	10	20	0	1	15	1	15	2	0	5	0	31	20	25	0

The Tuscan order is a simplification of the Doric. The proportions of the Doric are less sturdy than those of the Greek prototype and the shaft is often left unfluted. The Ionic order is more enriched than the Greek, and the capital is generally made uniform on all sides by placing the volutes anglewise. The Corinthian order was the favorite of the Romans, and was used in the largest temples. The Composite order was invented by the Romans. The capital, its distinctive feature, is a combination of the Ionic and Corinthian.

DRAWING THE ENTASIS OF A COLUMN.

The shafts of classic columns have a curved outline called the *entasis*. In the Roman orders the lower third is straight and vertical, and the upper two-thirds is curved. The shaft of the column is diminished one-sixth of its diameter at the neck. Fig. 3, representing the curved portion of the shaft of an Ionic column, shows a method for profiling the column. Draw the center line $a' b'$, and the base line $m' b'$; also, the upper line $k a'$, representing the neck of the shaft, at a distance of 11 modules above $m' b'$, making its length equal to the semi-diameter of shaft on that line, which is 25 parts. With b' as a center, and a radius of 1 module, describe the arc $m' w'$; through k draw a line parallel to $a' b'$, intersecting the arc at l'. Divide the arc $m' l'$ into 11 equal parts, as shown at 1, 2, 3, etc.; also, divide $a' b'$ into 11 equal parts and draw horizontal lines $1_1 w'$, $2_1 v'$, etc. From point *1* on the arc, draw a line parallel to $a' b'$; its intersection with the line $1_1 w'$ will give one of the required points. From *2* draw a similar line to 2_1, etc. All the points being marked, draw a curve through them by means of a spline, or flexible strip.

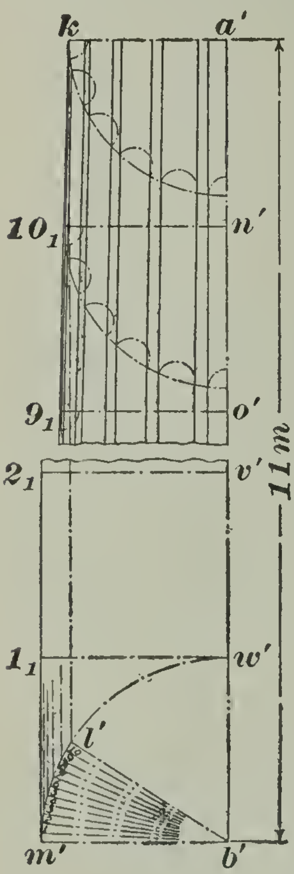


FIG. 3.

To draw the lines of the fluting of the upper portion of the shaft, proceed as follows: From points a', n', and o' in Fig. 3, with radii equal to the semi-diameter of the shaft at the section on which these points are located, describe quadrants. As the Ionic shaft has 20 flutes, divide each quadrant into 5 equal spaces of 18° each by means of the protractor; from these points, which will be the centers of the flutes, with a radius equal to $\frac{3}{4}$ of the length of arc between the centers of the flutes, describe the semicircles defining the

flutes. Project the lines of the fillets between the flutes to their position on the horizontal lines $k\,a'$, etc., by drawing lines parallel to the center line $a'\,b'$, and through the three points established for the edge of each flute draw a curved line by means of a spline.

MOLDINGS.

GREEK MOLDINGS.

The outlines of the Greek moldings follow the curves of the conic sections—the parabola, hyperbola, and the ellipse—and but rarely the circle. The Roman moldings are nearly always formed of circular arcs, and for this reason lack the delicacy and refinement that characterize the details of the Grecian monuments.

Greek moldings may be divided into three classes, according to the number of curves composing their outlines. In the first class are the following:

The *ovolo*, *echinus*, or *quarter-round* is shown at (a) Fig. 4. The point b, direction of the axis $a\,x$, and the coördinates $d\,a$ and $a\,b$, must be determined before the curve—which is part of a hyperbola—can be traced. Divide $a\,b$ and $b\,c$ into the same number of equal parts, and take the point x anywhere on the line $a\,x$—generally at a distance of from one to three times $a\,d$ from d, according to the curve required. Draw lines as shown, and trace the curve through the intersections. It is well to assume a point o through which the curve must pass, and draw a line from 3 through o, thus fixing the point x.

The *cavetto* or *cove* (b) is one-quarter of an ellipse. Let $a\,c$ and $a\,b$ be the required height and depth for the cove $b\,c$. Draw the large semicircle $c\,e$ with a radius equal to $a\,c$, and the small semicircle $b\,g$ with a radius equal to $a\,b$. Draw any radius, as a, g, e. From g erect a perpendicular, and from e draw a horizontal line intersecting at d, a point on the ellipse. Other points may be similarly found.

The *scotia* (c) is also an elliptic curve, having axes inclined to the vertical; it may be drawn as shown for the cavetto.

The *torus* (*d*) is also part of an ellipse, in which two points *d* and *c* are given, through which the ellipse must pass. Draw *e h* at any desired inclination through *d*. With any point as *a* as a center describe a semicircle passing through *d*. Draw *c m* perpendicular to *e h*; *c n* parallel to *e h*, and *a m n* cutting

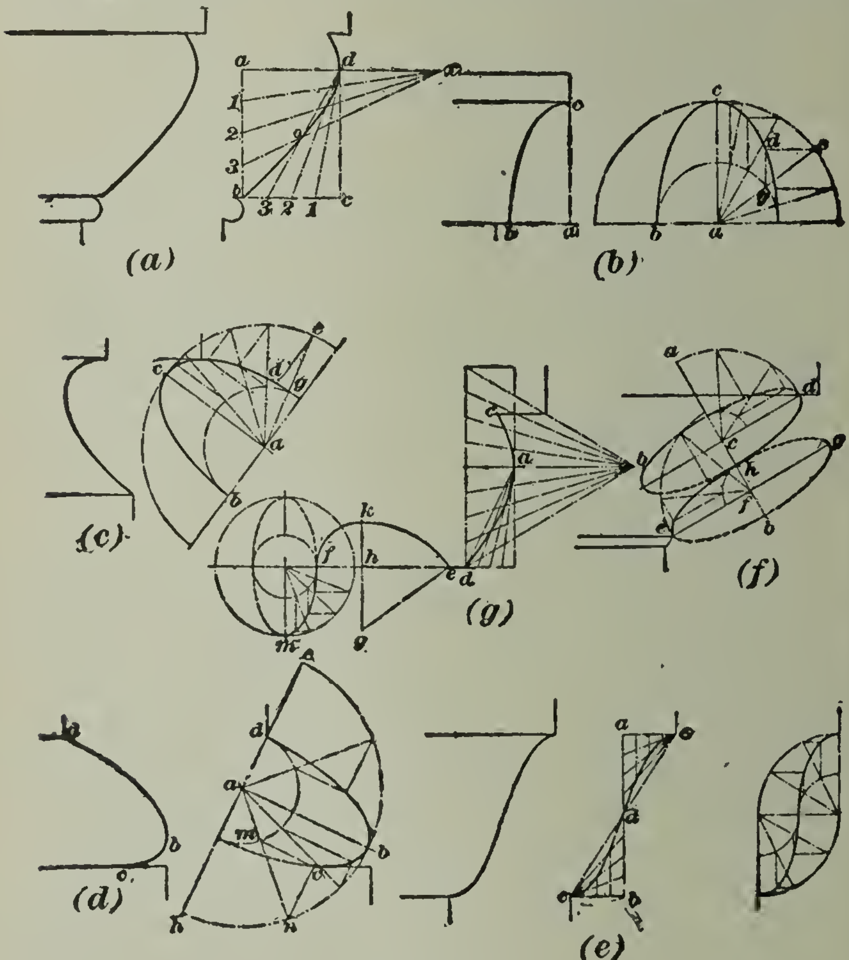


FIG. 4.

c n at *n*. Then the large circle must pass through *n*. With *a* as a center, and *a n* as a radius, draw the outside circle, and complete the ellipse as before shown.

In the second class, composed of two curves, are the following:

The *cyma recta*, shown at (*e*), is often made up of two arcs of parabolas. Make $a\,b$ equal to the required height, also $a\,e$ and $b\,c$, each equal to one-half of the required depth. Divide $a\,d$, $a\,e$, $b\,d$, and $b\,c$ into the same number of equal parts. Draw parallels to $a\,b$; also, the lines radiating from c and e, as shown. The curves may then be traced through the intersections. This molding, when more deeply cut, is sometimes made up of two reversed arcs of ellipses.

The *cyma reversa* (*f*) is often formed of reversed elliptic arcs. The inclination of the axis $a\,b$ may be taken to suit the curve required. Through d draw $d\,c$ perpendicular to $a\,b$; with $d\,c$ as a semimajor axis, and any suitable length, as $c\,h$, as a semiminor axis, draw the quarter ellipse $d\,h$. Through e draw $e\,f$ parallel to $d\,c$, giving f as the center of the second ellipse. With f as center, and $f\,h$ and $f\,e$ as radii, draw the inside and outside circles, and complete the curve with the quarter ellipse $h\,e$.

The third class of moldings are those consisting of three curves, and are generally made up of arcs of circles combined with arcs of ellipses. The *bird's-beak* molding, shown at g, belongs to this class. The principal curve $c\,a\,d$ is an arc of a hyperbola. The arcs of the circles $f\,k$ and $k\,e$ have their centers on the line $k\,g$, and are tangent. The arc $f\,m$ is a quarter ellipse.

Accessory moldings which may be used in connection with all the forms described are the *fillet*, which is the simple square band shown, crowning the cavetto in (*b*), and the *bead*, which is the small rope-like molding, rather more than a semicircle in section, shown at the base of the ovolo (*a*).

ROMAN MOLDINGS.

The Roman moldings are almost invariably profiled to the arc of a circle or of two tangent circles.

While the Greeks relied for effect on the graceful contour of their moldings, the Romans counted more upon the richness of carved ornament. Delicacy of execution in the Greek workmanship gave place to the mechanical and ostentatious in the decoration of Roman moldings. Besides this,

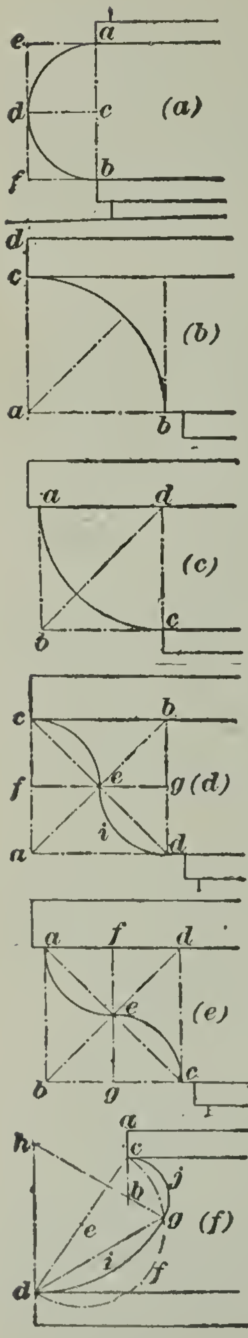


FIG. 5.

the execution of Roman moldings was often very careless. As a general rule, the lines of enrichment or carving on both Greek and Roman moldings corresponded to the profile of the surface on which it was carved.

The *torus*, shown at (*a*), Fig. 5, is semicircular, the center being at *c*, the middle point of the line *a b*.

The *cavetto* or cove, shown at (*b*), is a concave molding whose profile is a quarter circle. The center *a*, is found by extending the lines *d c* and *b a* until they intersect.

The *ovolo*, *echinus*, or *quarter-round*, shown at (*c*), is a convex molding with a quarter-circle profile, the center *d* being found as shown.

The *cyma recta*, shown at (*d*), is made up of two quarter circles tangent at *e*. The centers *f* and *g* are found by bisecting the lines *c a* and *b d*.

The *cyma reversa*, shown at (*e*), is the reverse of the cyma recta, which is concave above and convex below, while the former is convex above and concave below. The drawing explains itself.

The *scotia*, shown at (*f*), is drawn as follows: Having given the points *c* and *d*, draw *c d*, and bisect *c d* at *e*. With *e* as center and *e c* as a radius draw a semicircle *d f c*. Draw *d g* at an angle of 30° with the base fillet, cutting the arc at *g*. Erect a perpendicular at *d*, and with *g* as a center and a radius *g d* cut the perpendicular at *h*. Draw *g h* and drop a perpendicular from *c*, cutting *g h* at *b*. With *b* as a center and *b c* as a radius, draw the arc *c j g*. With *h* as a center draw the arc *g i d*, completing the curve.

INDEX.

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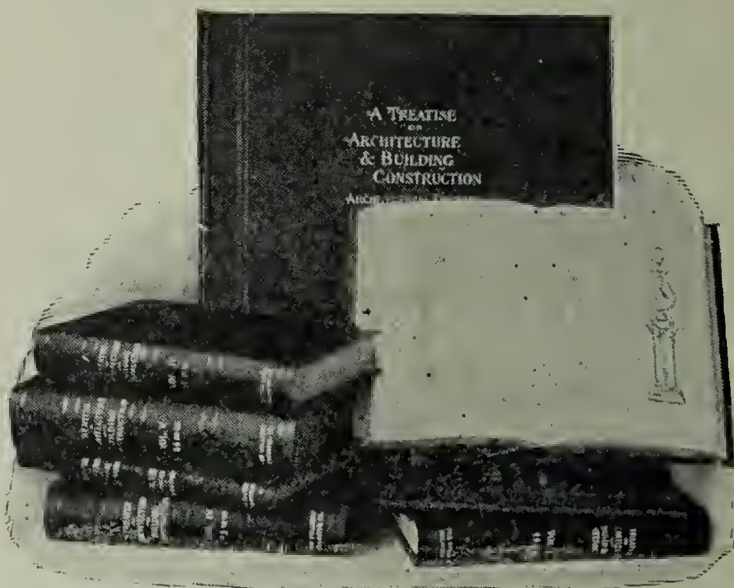

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Shop Practice Course.—This is divided into five parts, as follows: Machine-Shop Practice is intended for all those that wish to get a thorough knowledge of modern machine-shop practice. Toolmaking is intended for those that desire information in regard to the latest and most approved toolmaking methods. Patternmaking covers thoroughly every branch of patternmaking. Foundrywork gives thorough instruction in all phases of foundrywork. Blacksmithing and Forging is intended to give blacksmiths, helpers, etc. a thorough knowledge of the best methods employed in their trade.

Increased Salary Over 100 Per Cent.

Having been obliged to make my own way before I had a chance to get a practical education, I soon found that the man with the working education got the pay, while the others got the hard work. After studying from textbooks and at night schools with but little success, I enrolled in the I. C. S. Since I enrolled I have secured better employment, and my pay has been increased over 100 per cent. I am now first-class machinist for the U. S. Government.

HUGH J. WHITE, *Washington, D. C.*

The School of Mechanical Engineering

Refrigeration Course.—Graduates of this Course will understand the principles of refrigeration, the design and construction of refrigerating apparatus, and its installation, testing, and operation.

Gas Engines Course.—This is intended for all that desire to manufacture and install gas or oil engines, and for all that operate or repair them, or wish to qualify as gas engineers.

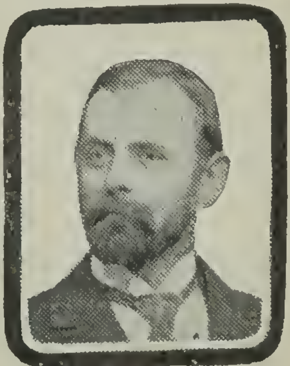
Farm Machinery Course.—This is intended for traction engineers, threshers, and farmers. Graduates will thoroughly understand the principles of operation of farm machinery and be able to run traction engines.

The School of Steam Engineering

Steam-Electric Course.—This is a complete Course on steam engineering and electric-lighting and railway work, and is intended for engineers, superintendents, etc. of large electric-lighting or railway plants.

Complete Steam Engineering Course.—This Course, as its name implies, is a complete treatise on stationary engineering, and is intended for engineers, superintendents, etc. in large steam plants using little or no electric apparatus.

A Chief Engineer's Opinion



I wish I could make my remarks about the I. C. S. Steam Engineering Courses strong enough to induce every engineer to enroll. The knowledge gained has been very valuable to me. I have the satisfaction of knowing not only the how but the why of my work. I now have charge of the Spring Garden Station of the Philadelphia Water Department, the largest plant owned by the city. The cost of an I. C. S. Course is insignificant.

CLARENCE D. WILLIASON,
1723 Norris St., Philadelphia, Pa.

The School of Steam Engineering

Advanced Engine Running Course.—This Course will qualify engineers, firemen, etc. to take charge of medium-sized steam plants.

Engine Running Course.—This Course is intended for engineers, firemen, helpers, etc. in small plants, and to qualify any one to get a start in steam engineering.

Engine and Dynamo Running.—This is intended for those who wish to qualify to operate and care for the apparatus in small steam-electric plants.

The School of Marine Engineering

Marine Engineers' Course.—This Course is intended for coal passers, firemen, water tenders, oilers, and other employes of steam vessels. The graduate will be qualified to pass marine license examination for any grade to which he is eligible by law.

The School of Locomotive Running

Trainmen and Carmen's Scholarships.—These three Scholarships provide trainmen with special instruction on air brakes, train rules, train heating, car lighting, etc.

What We Do for Marine Firemen

I had studied a good many versions of the so-called "Complete Treatise on the Steam Engine," but I had never found what I wanted to know until I enrolled in the Schools. Ten times what I have paid for my Scholarship would not buy my Course from me. I have risen from the position of fireman to that of chief engineer of an ocean-going steamer. Every promise you made has been faithfully kept, and you have even done more for me than I expected.

SHERMAN MALLERY, *Norfolk, Va.*

The School of Locomotive Running

Locomotive Running Scholarships.—These six Scholarships are very popular with locomotive firemen and engineers. They furnish instruction in the construction and management of the locomotive and its various appliances and fittings.

Air Brake Scholarships.—These five Scholarships are intended for enginemen and air-brake inspectors. They provide complete instruction on Westinghouse and New York air brakes.

The Roundhouse Scholarships.—These three Scholarships include either New York or Westinghouse air-brake instruction, together with instruction on locomotive boilers.

The School of Electrical Engineering

Electrical Engineering Course.—This is intended for superintendents of electrical establishments, factory artisans, draftsmen, designers, inventors, and all others that wish a thorough knowledge of the design of electrical apparatus.

Electrical Course.—This is intended for those that desire to qualify for any electrical position that does not require a knowledge of mechanical engineering.

Electric Railways Course.—This will qualify the student to construct and maintain electric railways under any system.

An Electrical Engineer's Experience

I have always thought the cost of my I. C. S. Electrical Course trifling compared with the benefits received. The last Papers of the Course on Electric Machine Design are especially valuable. Through the Schools, I was appointed electrician for Moncton, N. B. For some time I have been installing complete plants of all kinds, making the specifications myself. During the past year, I have had more work than I could handle.

GEO. M. MACDONALD,
Box 183, Moncton, N. B.

The School of Electrical Engineering

Advanced Electric Railways Course.—This Course is a complete treatise on steam engineering as applied to electric-railway plants, and is intended for superintendents, engineers, etc. in large electric-railway plants.

Advanced Electric Lighting Course.—This Course is a complete treatise on steam engineering as applied to electric-lighting plants. It is intended for superintendents, engineers, etc. in large electric-lighting plants.

Electric Lighting and Railways Course. — This is intended for dynamo tenders, stationary engineers, installation engineers, and all who work around electric-railway or lighting plants.

Electric Lighting Course.—This will qualify the student to successfully install and operate electric arc- and incandescent-lighting systems.

Dynamo Running Course.—This is a short but complete Course on the operation and care of dynamos. It is intended for dynamo tenders and for those who wish to get a start in electrical work.

Electric Car Running Course.—This Course will qualify the student to direct the equipment of a modern electric car, operate it safely under all conditions, and pass any motorman's or car inspector's examinations.

Interior Wiring.—This will qualify the student to do electric-light wiring and bellwork.

From Conductor to Head Barnman

I am a student in the Electric Car Running Course, and am pleased to say that the knowledge gained from my Course has enabled me to accept a much better position. When I enrolled, I was a motorman for the Ogdensburg Street Railway Company, but after applying myself to my Course for some time, I was promoted to head barnman for the above company, with a better salary, and have also been promised another increase.

John Henry O'Neill,
129 New York Ave., Ogdensburg, N. Y.

The School of Electrotherapeutics

Complete Electrotherapeutic Course.—Graduates of this Course will be qualified to make all modern and approved applications of the electric current in the diagnosis and treatment of disease.

Neurological Electrotherapeutic Course.—This is intended for physicians and medical students that desire a knowledge of the treatment by electricity of the diseases of the brain, spinal cord, peripheral nerves, and muscles.

Gynecological Electrotherapeutic Course.—This is intended for physicians that wish to make a special study of the diseases peculiar to women.

Surgical Electrotherapeutic Course.—This is intended for surgeons and general practitioners.

Eye, Ear, Nose, and Throat Electrotherapeutic Course. This is intended for physicians and specialists.

Dental Electrotherapeutic Course.—This is a complete up-to-date treatise on electricity as used in dental operations.

Roentgen Rays Course.—This includes instruction in the manipulation and care of all up-to-date apparatus used by recognized Roentgen ray workers.

Nurses' Electrical Course.—The information contained in this Course will increase the efficiency and earning capacity of any nurse, and will make her more valuable to the attending physician.

Genito-Urinary Electrotherapeutic Course. — This Course is especially intended for the genito-urinary specialist.

Prominent Physicians Commend Our Course

International Correspondence Schools,
Scranton, Pa.

Gentlemen:—After having completed the Electrotherapeutic Course I can tell you that this Course is, in my opinion, a wonderful piece of work. The physician finds everything for intelligently applying electricity, and at the same time is not bothered with superfluous things—hypothesis, opinions, names, etc. I call them superfluous in a practical Course which aims at nothing but giving the student a thorough knowledge of electricity so far as it is used as a therapeutic and diagnostic agent.

Dr. A. Decker, *425 Orchard St., Chicago, Ill.*

The School of Telephone and Telegraph Engineering

Telephone Engineering Course.—This Course will qualify students to maintain and manage telephone switchboards and exchanges, make repairs anywhere in the system, and take general supervision of a plant.

Telegraph Engineering Course.—This is intended for telegraph operators in commercial or railroad business, the military or the signal service. It gives thorough instruction in all branches of telegraphy. Graduates will be qualified to fill the most responsible positions.

The School of Civil Engineering

Civil Engineering Course.—This Course is intended for practicing bridge, railroad, municipal, or hydraulic engineers, surveyors, and engineers' assistants that wish to review former studies, to acquire a thorough knowledge of other branches of the profession by studying those special branches of engineering in which they lack knowledge, or to become qualified as consulting engineers. The instruction is sufficiently advanced and comprehensive to insure to the graduate the technical training necessary to the successful prosecution of his professional work.

Responsible Position Before He Finished Study

I wish here to say that before I had finished the instruction in "Batteries," in the I. C. S. Telephone Engineering Course, the Schools helped me to obtain the position I now occupy, that of assistant electrician for the American Bell Telephone Company, at Goshen, Ind. The only recommendations I carried were the Schools' records of my progress in the Course, as far as I had gone. My technical training has been conducted by mail entirely.

W. H. Fox, *Goshen, Ind.*

The School of Civil Engineering

Bridge Engineering Course.—This is intended for surveyors, draftsmen, bridge engineers, and their assistants, and employes in bridge works. Graduates will, with some experience, be able to design and superintend the construction of modern highway and railroad bridges.

Surveying and Mapping Course.—This is intended for rodmen, chainmen, engineers' assistants, and all that wish to become surveyors. Graduates will be qualified to survey railroads, farm properties, etc.

Railroad Engineering Course.—Graduates of this Course will have the necessary education to survey and map out proposed locations for railroads, or to fill responsible positions in the work of construction or the maintenance-of-way department.

Hydraulic Engineering Course.—This is intended for those interested in irrigation, water supply, etc. Graduates will have the necessary education to design and install water-power plants, hydraulic machinery, and water-supply and irrigation systems.

Municipal Engineering Course.—This is intended for municipal engineers and contractors, city surveyors, and their assistants. It will qualify the student to survey and make maps and estimates of proposed sewerage systems, street improvements, pavements, etc., and to superintend their construction.

Earned $30 as Teacher: Earns $100 as Surveyor

When I enrolled in the I. C. S., I was teaching school at $30 a month. After studying three months, I secured a position as draftsman and assistant surveyor at $70 a month, but soon after beginning work was offered $100 a month. In his spare time a man can gain as good an education in the International Correspondence Schools, Scranton, Pa., as at the best colleges. I heartily recommend the Schools.

LLOYD G. SMITH,
Deputy County Surveyor,
Chinook, Choteau Co., Mont.

The School of Mathematics and Mechanics

This is our largest School. In it are made all the preliminary examinations and corrections in mathematics and mechanics for the other Schools. The Principal is assisted by 13 Special Instructors and 130 Examiners.

While most of the mathematical subjects are taught in connection with other Courses, the following can be taken separately:

Arithmetic Course, Part 1.—This Course includes instruction from the simplest definitions of Arithmetic up to and including ratio and proportion.

Arithmetic, Parts 1 and 2.—This Course includes all the subjects in Part 1, together with instruction in the subjects: Percentage, Interest, Notes, Bank Discount, Stocks and Bonds, Average or Equation of Payments, Partnership, and Alligation.

Algebra Course.—This is a thorough Course in Algebra, including instruction in Quadratic Equations, the Remainder Theorem, the Binomial Formula, Progressions, Logarithms, etc.

Advanced Algebra Course.—This Course is intended for teachers of Algebra, for engineers, and for all others that desire thorough instruction in higher algebra.

Kellar, the Greatest Living Magician, Testifies

MONTOUR HOUSE,
Opposite Court House,
J. L. RIEHL, *Proprietor.*

DANVILLE, PA., May 2.

DEAR SIR:—In reply to your request for my opinion regarding the International Correspondence Schools, I beg to say that I consider the system of Instruction the very best that can be desired, and judging from their Course in Arithmetic, in which I am enrolled, I think any one of ordinary intelligence can acquire a thorough knowledge of mathematics by carefully reading and observing the rules of the Instruction Papers. The system is so very simple that any one who can read may learn.

Yours truly,
HARRY KELLAR (Magician).

The School of Chemistry

General Chemistry Course.—This is a Course in general and analytical chemistry, and is intended for those who desire to obtain a general knowledge of chemistry and analytical methods and thus prepare, in as short a time as possible, for general laboratory work. Since the Course includes an exhaustive treatment of organic chemistry, it enables the student to prepare for responsible positions in the manufacture of coal-tar products and various other organic materials. This Course also prepares the student for such positions as pharmaceutical chemist, toxicologist, etc.

Chemistry and Chemical Technology.—The student in this Course receives, in addition to a thorough training in general and analytical chemistry, full detailed instruction in the most important branches of applied chemistry.

Separate Courses in the following branches of applied chemistry are given: Chemistry and Manufacture of Sulphuric Acid; Chemistry and Manufacture of Alkalies and Hydrochloric Acid; Chemistry and Manufacture of Iron and Steel; Chemistry and Packing-House Industries; Chemistry and Manufacture of Cottonseed Oil and Products; Chemistry and Manufacture of Leather; Chemistry and Manufacture of Soap; Chemistry and Manufacture of Cement; Chemistry and Manufacture of Paper; Chemistry and Manufacture of Sugar; Chemistry, Petroleum, and Manufacture of Products; Chemistry and Manufacture of Gas.

Drug Clerk Becomes a Chemist

I started early in life to earn my living by clerking, and my lot was cast in a drug store. Before I enrolled in the Chemistry Course, I made several attempts to educate myself, but with little success. Thanks to the Schools, I have mastered chemistry to a degree that my ambition had never pictured. Soon after taking up my Course, I took charge of the laboratory at E. E. Bruce & Co., wholesale druggists, at a good salary, which has since been increased 45 per cent.

H. B. Molyneaux, *Omaha, Neb.*

The School of Drawing

Mechanical Drawing Course.—The student that completes this Course will be able to execute neat mechanical drawings. We have met with remarkable success in teaching this subject to thousands entirely ignorant of drawing, hundreds of whom are now earning good salaries as draftsmen and designers. We guarantee to qualify ANY ONE to make neat mechanical drawings that follows our directions.

Architectural Drawing Course.—The student that completes this Course will be able to make general and detail drawings of architectural structures, and will be thoroughly qualified to take a position in an architect's office. We guarantee to qualify ANY ONE to make neat architectural drawings that follows our directions.

If you wish to learn Mechanical or Architectural Drawing, or desire to become a mechanical or electrical engineer, or architect, and support yourself while learning either of these professions, send for special circular entitled "Support Yourself."

Drawing Outfit Free

Every student in either of these two Courses is furnished with the Complete Drawing Outfit No. 1, valued at $13.55. He is permitted to retain this Outfit for use indefinitely, provided he observes the terms of his Contract for Scholarship.

From Dentist to Draftsman

When I enrolled in the I. C. S. Mechanical Drawing Course, I was practicing dentistry. After partially finishing my Course, I commenced making drawings for the Smith Metallic Packing Co., occasionally receiving as high as $15 for a single drawing, and having some of my work taken in preference to that done by the Master Mechanic of a Mexican railway. I have now become Chief Draftsman for the Smith Metallic Packing Company, Chicago.

M. E. HOAG,
861 Monadnock Bldg., Chicago, Ill.

The School of Architecture

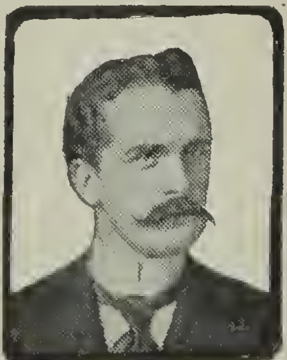
Complete Architectural Course.—This is intended for architects, draftsmen, contractors and builders, carpenters, masons, bricklayers, building tradesmen, and all others desirous of qualifying themselves to design and construct buildings. Graduates will be able to design, prepare working drawings and specifications for building operations, calculate quantities, estimate costs, and will have a thorough knowledge of iron and steel construction.

Architectural Drawing and Designing Course.—This is intended for carpenters, contractors, architectural draftsmen, and all that wish to learn architectural drawing, history, and design.

Building Contractors' Course.—This will qualify carpenters, masons, bricklayers, and other building tradesmen to make and read plans, estimate accurately, and undertake general contracting and building. This is a practical Course in building construction, containing practical instruction for practical men.

Architectural Drawing Course.—This Course is described under "The School of Drawing." See previous page. Students in this Course have been so successful that we will forfeit $100 to any student of our Architectural Drawing Course that will study as we direct, whom we cannot qualify to make neat architectural drawings.

From Telegraph Operator to Architect



When I began studying in the Complete Architectural Course of the International Correspondence Schools, of Scranton, Pa., I was a telegraph operator and knew nothing whatever of drawing, or of the profession that I am now following. I have given up my partnership at Fairmount and am now well established here, with good prospects for a very successful business. My income at present is three times what I was receiving when I enrolled.

JOHN C. TIBBETTS, *Grafton, W. Va.*

The School of Design

Ornamental Design Course.—This provides instruction in freehand drawing, sketching from nature, and conventionalizing of natural forms as a basis for decorative design, history of ornament, details of color, and construction of all typical elements, composition, pencil, pen, wash-drawing and water-color work, and the application of design to china, wall paper, lace, book covers, embroidery, furniture, stained glass, interior decoration, rugs, carpets, oilcloths, etc. The instruction is carefully graded from the simplest instrumental work to the more complicated water-color rendering of practical designs.

Drawing, Sketching, and Perspective Course.—This is intended for teachers that wish to qualify for the position of drawing inspector; also, for all that desire a thorough knowledge of freehand and perspective drawing. Even if the Course is taken only for developing artistic tastes and perceptions, it is invaluable.

The School of Sheet-Metal Work

Sheet-Metal Pattern Drafting Course.—This Course is intended for tinsmiths, cornice makers, architectural sheet-iron workers, coppersmiths, plumbers, etc. Graduates will be able to develop all kinds of sheet-metal patterns.

The School of Plumbing, Heating, and Ventilation

Sanitary Plumbing, Heating, and Ventilation Course. This affords an education in plumbing, heating, and ventilation that will qualify any plumber, steam fitter, or gas-fitter to fill the highest positions in his line of work. It is of particular value to such men as aspire to become master plumbers, general contractors, or heating engineers.

Sanitary Plumbing and Gas-Fitting Course.—This Course enables plumbers, gas-fitters, and apprentices to do their work easier, better, and more economically, and to pass examinations for license.

Heating and Ventilation Course.—This is intended for steam fitters, plumbers, and heating and ventilating engineers. It will qualify the student to install any system of heating or ventilation.

Sanitary Plumbing Course.—This is intended for plumbers and plumbing apprentices that do not care to study gas-fitting or heating and ventilation. It will qualify the student to pass any examination required of plumbers.

Gas-Fitting Course.—This will qualify the student to calculate illumination required, test systems, put up combination fixtures, or make drawings of proposed installations.

From Journeyman to Master Plumber and Gas-Fitter

I am under many obligations to the I. C. S. I have recently passed an examination and obtained a first-class Master Plumber's license. It has been of inestimable benefit to me. I most heartily recommend the Schools, especially to plumbers who are desirous of gaining an insight to the technical theories of the trade, which equips them to earn larger wages and the best positions as workmen.

MICHAEL L. SYLVIA,
Plumber and Gas-Fitter,
New Bedford, Mass.

The School of Mines

Full Mining Course.—This is intended for mine superintendents, foremen, mining engineers, and others that wish a thorough education in all branches of coal and metal mining. It fits the student to superintend either coal or metal mines, or to pass mine foreman's or State Mine Inspector's examinations.

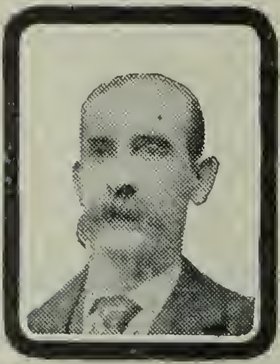
Complete Coal Mining Course.—This is intended for mining engineers, mine officials, and miners that wish a complete education in the methods and machinery used in coal mining. It embraces a study of every detail necessary to fit a student for any position in or around either anthracite or bituminous mines, or pass the examinations for mine foreman or State Mine Inspector.

Short Coal Mining Course.—This contains only the information absolutely necessary to qualify persons to pass the mine foreman's examinations, and those that finish it will have a good knowledge of the art of mining.

Metal Mining Course.—This is intended for mine officials, metal miners, or men engaged in ore dressing and milling. It qualifies the student to take charge of modern metal mines or mining and milling machinery.

Metal Prospectors' Course.—This will qualify the student to make assays of ores and prospect for gold, silver, and other valuable minerals.

Salary Increased $500 Per Year



Before I had finished the Complete Coal Mining Course, I obtained a first-grade Certificate of Competency as mine foreman, and also a position where my salary was increased $500 per year. I am successfully handling the mine in which I am employed as inside manager and foreman. From the information gained in my Course, I can master the most complicated problems in mine management, and do all my own surveying and platting.

JAMES PARTON,
Monongahela City, Pa.

The School of Metallurgy

Complete Metallurgy Course.—This Course is intended for metallurgists, investors, and others who desire a knowledge of the metallurgy of gold, silver, copper, lead, and zinc. It will give the student a broad field of usefulness and will enable him to direct metallurgical operations of any kind whatever.

Milling Course.—This provides instruction for millmen, bosses, and superintendents of milling operations, and will thoroughly qualify the student for the highest positions in this particular branch of metallurgy. The Course deals with the dry methods of gold and silver extraction.

Hydrometallurgical Course.—This Course fully explains the wet methods of treating ores for gold and silver extraction, and also includes thorough instruction in electrometallurgy. It is intended for helpers, foremen, and superintendents in hydrometallurgical work, electrochemists, electricians, etc.

Smelting Course.—This Course deals with the preliminary treatment and the reduction of ores of the common metals and the refining of the crude products. Graduates of this Course will be qualified to take charge of all kinds of smelting operations.

The School of Commerce

Failed Before; Succeeded With Us

I had attended night school and had spent nearly $100 on textbooks without success before I heard of the I. C. S. The only thing I am sorry for is that I did not hear of them sooner. I had no trouble in understanding the Complete Commercial Course that I took; my instructors taught me everything by mail easily, simply, and accurately. The value of what I learned is shown by the fact that during the year my salary has been increased 25 per cent.

ERNEST BRUNELLI,
Gardiner, N. Mex.

The School of Commerce

Complete Commercial Course.—This Course is intended for young men or women, in the city or country, that wish to equip themselves with a business education. Graduates will be able to keep books by single or double entry, or perform the work of stenographer or correspondent. They will also have a thorough knowledge of modern office methods, card systems, etc., as used by the most successful and up-to-date commercial houses.

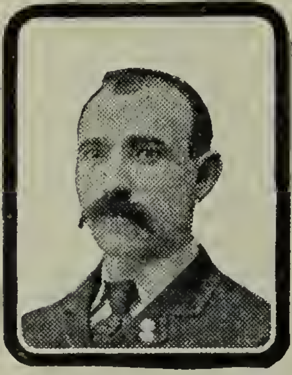
Bookkeeping and Business Forms Course.—This Course is intended for bookkeepers, stenographers, etc. that wish a business education. Many professional bookkeepers have taken this Course to get the up-to-date labor-saving methods that it contains.

Complete Stenographic Course.—This Course will qualify the student for the position of stenographer. Faithful study and practice will enable him in a few months to acquire the necessary speed, and, as competent stenographers are always in demand, he can readily secure a good position.

The School of English Branches

English Branches Courses.—These Courses, two in number, are intended for those that lack a common-school education, or wish to try Civil-Service Examinations.

Success Won From Defeat



I made three attempts to improve myself at night school, but gave up each time, as I was so backward. So up to 1895 I could only write my name and read a little. I then took the English Branches Course and can now write and spell well. While studying, I worked 84 hours per week, as in the steel business it is necessary to work Sundays. I am now a foreman, and my salary has been increased 60 per cent. My ability to hold the position is due to the Schools.

MICHAEL SULLIVAN, *Latrobe, Pa.*

The School of Textiles

Complete Cotton Course.—This Course is intended to qualify those that complete it for the position of superintendent, or purchasing or selling agent, of a cotton mill. It will also greatly increase the efficiency of agents, superintendents, overseers, second and third hands, mechanics, spinners, loom fixers, weavers, and all other workers in a cotton mill.

Cotton Carding and Spinning Course.—This is intended for yarn-mill superintendents, carders, spinners, section hands, card grinders, and all employed in cotton-yarn mills. It is also recommended for cotton-machinery erectors, yarn agents, hosiery-mill superintendents.

Cotton Designing Course.—This Course is intended for designers and assistant designers, agents, superintendents, overseers, and second hands in weave rooms; section hands, loom fixers, weavers, in cotton mills; dry-goods merchants, salesmen in commission houses, jobbers, and all men or women working in cotton mills, interested in cotton designing, or desirous of qualifying for any of the foregoing positions.

Cotton Spinning and Warp Preparation Course.—This is intended for superintendents of thread mills, boss spinners, second and third hands in spinning rooms, overseers of beaming, slasher tenders, and all men employed in cotton-yarn mills.

A Shipping Clerk's Advancement

As a result of your training by mail I am at present bookkeeper for the Randolph Manufacturing Co., at Franklinville, N. C. When I enrolled in your Complete Cotton Course I was working as shipping clerk for the same concern, at a salary only half what I am now receiving. I heartily indorse instruction by mail in Textile Design, as conducted by the I. C. S. The lessons are plain and to the point, and contain only information that is valuable.

HUGH PARKS, *Franklinville, N. C.*

The School of Textiles

Cotton Warp Preparation and Plain Weaving Course. This is intended for superintendents of weave mills, boss weavers, fixers, second and third hands in weave rooms, weavers, slasher tenders, etc. It is also recommended for those having a good knowledge of yarn-mill machinery that wish to qualify as general mill superintendents.

Fancy Cotton Weaving Course.—This Course is intended for designers and assistant designers, agents, superintendents, overseers, and second hands in weave rooms, section hands, loom fixers, weavers, and all others that desire a knowledge of warp preparation and weaving machinery for fancy goods.

Cotton Carding, Spinning, and Plain Weaving Course. This Course is intended for those that desire to qualify for the position of superintendent or overseer in mills making plain cotton goods.

Theory of Textile Designing Course.—This is intended for those that have a good knowledge of warp preparation and weaving machinery, but whose knowledge of the theory of designing is not complete. It is recommended to boss weavers, overseers, second hands, and others that desire instruction on the analysis and reproduction of fabrics, and the drafting of designs. Almost every textile designer in the country is hampered in his business by the lack of competent designers.

A Mill Worker's Advancement

When I enrolled in your Cotton Carding and Spinning Course I was section hand in the card room of Mill No. 3 of the Eagle & Phoenix Mill Co., of Columbus, Ga. I am now second hand in their Mill No. 1. Your training has increased my salary and bettered my prospects. Correspondence instruction is the only means by which millmen may qualify themselves for promotion. My advice to ambitious young men is that they enroll in the I. C. S. and study in their spare time.

A. W. PITTS, *Phoenix City, Ala.*

The School of Textiles

Complete Textile Designing Course.—This is intended for designers, assistant designers, agents, superintendents, overseers, and second hands in weave rooms; and for section hands, loom fixers, and weavers in cotton, woolen, worsted, or silk mills.

Woolen and Worsted Designing Course.—This Course is intended for designers and assistant designers, agents, superintendents, overseers, and second hands in weave rooms; section hands, loom fixers, and weavers in woolen and worsted mills; dry-goods merchants, salesmen in commission houses, jobbers.

Complete Woolen Course.—This Course is intended for agents, superintendents, overseers, and section hands in woolen mills, master mechanics, weavers, loom fixers; in fact, for any that hold a position in a woolen mill.

Woolen Carding and Spinning Course.—This is especially recommended to superintendents, boss carders, boss spinners, section hands, card and mule erectors, woolen-machinery salesmen, woolen-yarn agents and merchants, and also for the superintendents and overseers of knitting mills using woolen yarns.

Woolen Warp Preparation and Weaving Course.—This is intended for all that desire a knowledge of the preparing of woolen warps, and the weaving and elementary designing of woolen goods.

Promoted to Pattern Weaver

When I enrolled for your Textile Designing Course I was a weaver. Since then, the instruction I have gained from it, together with my practical experience, has enabled me to advance to the position of pattern weaver, with the Springville Manufacturing Company. As a result of my experience, I am free to state that I consider your correspondence instruction in the manufacture of textiles to be all that is claimed for it.

C. W. Seifert,
128 West Main St., Rockville, Conn.

The School of Pedagogy

Teachers' Course.—This Course is intended especially for men and women that wish to qualify for remunerative and responsible positions in the teaching profession.

Methods of Teaching Course.—This Course provides teachers with thorough instruction in the best modern methods of teaching, and enables them to qualify for the highest salaried positions.

Drawing, Sketching, and Perspective Course.—This is described under the School of Design, page 22.

The School of Lettering and Sign Painting

Lettering and Sign Painting Course.—This is intended for sign painters, window dressers, designers of lithographs, book and magazine covers, advertising matter, etc., wood and metal engravers, jewelers, stone cutters, wood carvers, draftsmen, stencil makers, retail merchants, clerks, and all others that wish a knowledge of correct styles of lettering.

Show-Card Writing Course.—This is intended for business men, clerks, window trimmers, letterers, and all others that desire a knowledge of effective and artistic show-card writing. It includes the only complete and up-to-date instruction on the subject that has ever been prepared.

Lettering Plates Are Unexcelled

I think your Course is the most satisfactory that can be given. The Bound Volumes constitute a reference library that is the best to be had, and even if I did not go through the Course, I have it printed so plainly that I could teach myself without assistance, and your lettering Plates are unexcelled; they are the correct thing. My position now is Sign and Ticket Writer for the Robert Simpson Co., Limited, Department Store, of Toronto. SIDNEY SMITH,
414 Ossington Ave., Toronto, Ont., Can.

The School of French

French Course.—This is intended for people of culture, civil engineers, business men, and all that desire a conversational knowledge of the French Language. The Course is taught by a system of instruction with the phonograph, designed and used only by the Schools.

The School of German

German Course.—This is taught with the aid of the phonograph, and is intended for professional and business men and all that come in contact with German-speaking people.

The School of Spanish

Spanish Course.—This Course is intended for lawyers, physicians, professional and business men, and all those whose duties bring them in contact with the Spanish-speaking people of South America, Cuba, Philippines, or Spain. This Course is taught with the aid of the phonograph.

The School of Navigation

Ocean Navigation Course.—This Course will qualify seamen, etc. to pass examinations for master or mate of ocean-going vessels. It is the most complete Course on this subject that has ever been published, and graduates of this Course will be qualified to pass any nautical examination in the United States or foreign countries.

Lake Navigation Course.—This Course is intended particularly for those that wish to pass examinations for masters or pilots of lake and coast vessels, and also for those that wish to increase their grade of license. It is the first and only Course on this subject that has yet appeared. Graduates of this Course will be qualified to pass examinations for master's or pilot's license for vessels engaged in lake and coast navigation.

The School of Advertising

Advertising Course.—This Course is designed to teach the student how to analyze any article of merchandise, find its selling points, and write and lay out a first-class ad that will so present these selling points as to impel the reader to become a purchaser of the article advertised.

The Course also includes instruction in the preparation of miscellaneous retail advertising matter; retail advertising management; department-store advertising; and the establishment of an ad-writing business to be conducted at home or in an office. The Course is designed to qualify the student to write good advertising for any or all retail lines of business, including department stores, and to train him for later advancement to the position of advertising manager.

The School of Window Dressing

The Window Dressing Course.—This Course is an elaborate treatise on window dressing, store decoration, etc. in all its branches. It embraces practically every form of commercial decorative treatment, for nearly all classes of business. The Course is an epitome of the ideas and writings of the most prominent decorators in this country. This Course will not only advance the window dresser to the front ranks of his profession, but will also qualify any one to become a competent window dresser.

The School of Law

Commercial Law Course.—This Course is designed to aid persons to become better equipped to conduct their business; through it an opportunity is offered them to attain a knowledge of the well-established legal rules and principles that apply to and govern business transactions.

The Course will be found especially useful by the following: Law students, mercantile persons, manufacturers, superintendents, bankers, insurance officials, bookkeepers, administrators, justices, conveyancers, etc.